FINAL REPORT

Evaluation of Gasoline and Diesel Fuel Options for Maricopa County

for

State of Arizona
Department of Environmental Quality

performed under

Contract 97-0013AA

by

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EXECUTIVE SUMMARY

MathPro Inc. (prime contractor) and Energy & Environmental Analysis, Inc. (sub-contractor) have conducted a technical and economic analysis of various gasoline and diesel fuel formulations aimed at decreasing vehicle emissions of

- Carbon monoxide (CO) emissions in the Winter season (November 1 – March 31); and
- Volatile organic matter (VOC), nitrogen oxides (NOx), and particulate matter (PM), year-round.

Gasoline and Diesel Fuel Formulations Evaluated

Exhibit ES-1 (at the end of the Executive Summary) shows the five (5) gasoline formulations and six (6) diesel fuel formulations evaluated in this study.

The first four gasoline formulations are variants of Arizona Cleaner Burning Gasolines (CBG) Type 1 (corresponding to federal RFG2[1]) and Type 2 (CARB RFG2). As such, they meet hybrid standards – *property-based* and *performance-based* – for emissions reduction. The last gasoline formulation meets a *performance-based* standard for CO emission reduction, as requested in the Statement of Work (SoW). All of these gasolines would be *conventional gasolines* under the anti-dumping provisions of the federal RFG program.

The diesel fuel formulations encompass all of the options specified in the SoW, except for oxygenated diesel fuel. Oxygenated diesel fuels produced in the required volumes with current technology would be prohibitively expensive in Maricopa County; hence, the Subcommittee (in its meeting on December 29, 1997) dropped this option from consideration.

Baseline Fuels

The baseline gasoline and diesel fuel for the analysis reflect "business-as-usual" in Maricopa County, starting with the 1999 Summer season. "Business-as-usual" for Maricopa County encompasses gasoline and diesel fuel programs unique to Maricopa County and, in the case of gasoline, year-to-year changes in standards from 1997 through 1999. In particular, the baseline fuels are consistent with:

- The *gasoline standards* in place for the 1999-2000 Winter season: Arizona Cleaner Burning Gasolines, CBG Type 1 and CBG Type 2;

1 We use "federal RFG2" to denote federal Phase 2 RFG. The more common designation is "federal RFG II".

- The *diesel fuel standards* in place now: EPA diesel, for on-road and off-road use; and

- The *current pattern of fuel supply* to Maricopa County from the two main sources – the Los Angeles refineries (via the Santa Fe Pacific Pipeline (SFPP) West pipeline system from Los Angeles through Colton) and the West Texas/New Mexico refineries (via SFPP's East pipeline system through El Paso and Tucson).

"Current pattern of fuel supply" denotes (1) the current West and East shares of gasoline and diesel fuel supplies to Maricopa County – not necessarily the volume shares of any given refiner or marketer – and (2) the current predominance of CBG Type 3 in the Maricopa County market.

In establishing baseline fuel properties, we assumed no significant change between now and 1999 in the relative volumes (and individual refiners' shares) of West and East supplies. Likewise, we assumed that – with business as usual – most of the gasoline supplied to Maricopa County would be CBG Type 1 gasoline (rather than CBG Type 2) in 1999 and later years, because CBG Type 1 is less costly to produce in most refineries.

Key Results and Findings: Costs, Emissions Effects, and Cost-Effectiveness

The key results and findings of the study with respect to estimated costs and changes in vehicle fleet emissions are summarized in **Exhibits ES-2** (gasoline, Winter season), **ES-3 (**diesel fuel, Winter season**)**, and **ES-4** (diesel fuel, Summer season).

The exhibits show the estimated cost-effectiveness measures of the fuel formulations considered, by year, in $K per metric ton (mt) of emission reductions.

- Gasoline: **$K /metric ton CO**

- Diesel Fuel: **$K /metric ton (PM (total) + NOx + VOC + 1/7(CO))** and **$K /metric ton (PM (primary))**

The first of the diesel fuel measures was developed by CARB in connection with cost-effectiveness analyses involving multiple pollutants.[2] The second customary for estimating the cost-effectiveness of programs aimed at direct (as opposed to total) PM-10 emissions.
The estimates in Exhibits ES-2, ES-3, and ES-4 should be viewed as indicators of the relative costs and merits of the various fuel formulation options (not as precise assertions of costs or benefits). They offer a means of rank ordering the various fuel formulation, with respect to the technical and economic factors considered in this study.

2 The numerical values shown in the exhibits are computed so as to avoid double counting the small contribution to total particulates of secondary nitrates formed from NOx.

Gasoline

- **CBG Type 1 (30 ppm sulfur), CBG Type 2 (3.5 wt.% oxygen)** and **CO Performance Standard gasolines** (**G2, G4,** and **G5**) show the best cost-effectiveness for CO emission reduction. Of the three, **G2** offers the lowest per-gallon cost and daily cost, but provides the least CO emission reduction (about 20 tons/day in 2001 and 17 tons/day in 2010). **G4** has the highest cost, but offers the most CO emission reduction (about 33 tons/day in 2001 and 28 tons/day in 2010. **G5** is intermediate with respect to both cost and CO emission reduction. All three gasolines are low in sulfur and high in oxygen content, the two most important determinants of CO emission reductions in gasoline vehicles.

- **CARB RFG2 (2.0 wt.% oxygen)** (**G3**) shows the worst cost-effectiveness. It has essentially the same sulfur content as the **G2**, **G4**, and **G5** formulations, but lower oxygen content. As a result, it delivers lower CO emission reductions than the other low sulfur gasolines. And, it has the highest refining cost.

- **CBG Type 1 (80 ppm sulfur)** (**G1**) offers low refining and mileage costs and intermediate cost-effectiveness, and it has the lowest aggregate cost to Maricopa County. However, it delivers little CO emission reduction (≈ 0.4%).

- All of the other gasolines deliver small CO emission reductions, ranging from about 2% (**G3)** to about 5% (**G4)**).

- All of the gasolines deliver only small PM_{10} reductions (about 0.5% for **G1** and about 1% for the others).

Diesel Fuel

- **EPA Diesel (100 ppm sulfur)**, **CARB Diesel (average certified properties)**, and the **Advanced Diesel Blend** (**D2**, **D4,** and **D5**) show the best cost-effectiveness with regard to combined emission reductions of the formulations analyzed. Of the three, **D2** is the most cost-effective, but offers the lowest emission reductions. **D5** has the highest per-gallon and daily cost, but offers the most emission reductions. **D4** is intermediate with respect to both cost and combined emissions reduction.

- **CARB Diesel (formula properties)**, and **Swedish Class 1 Diesel** (**D3** and **D6**) show similar and inferior cost-effectiveness with regard to combined emission reductions. **D6** offers the most emission reductions of any of the formulations, but is by far the most expensive; **D3** offers intermediate emission reductions, but at a high cost.

- **EPA Diesel (cetane enhanced) (D1**) has intermediate cost-effectiveness relative to the other diesel fuel formulations. **D1** is the least expensive but offers low emission reductions relative to the other diesel fuel formulations.

- The combined emissions reductions offered by the diesel fuel formulations range from about 0.2% to 2½% of total baseline combined emissions.

Key Results and Findings: Timing

Under Business-As-Usual Conditions

With business as usual (as defined above), the likely first availability – *in volumes sufficient to meet Maricopa County demand* – of the fuel formulations would be as follows:

- Gasoline: Winter 2001-2002 or Winter 2002-2003

- Diesel fuel: Summer 2001 or Winter 2001-2002

This finding is based on the requirements for capital investment indicated by our analysis, the lead time for making capital investments, and the "trigger date" for undertaking such investments.

Under Transient Conditions

Some of the fuel formulations – for example, CARB RFG2 or CARB diesel fuel – likely could be supplied sooner, if the State of Arizona mandated an early start date. In response to such a mandate, the refining industry *at large* could establish new production and distribution operations to meet Maricopa County demand for the new formulation. Such a situation would involve an increase (possibly an excursion) in the cost of supply, at least for some transition period.

With timely completion, the proposed Longhorn pipeline (discussed in the next section) *could* influence the time of availability of certain fuel formulations. For example, the pipeline could make CBG Type 1 (80 ppm sulfur) available to Maricopa County earlier than what is indicated above. The West refining center can produce CBG Type 1 gasoline (80 ppm sulfur) for Maricopa County now; the East cannot. If the Longhorn pipeline were in place, Gulf Coast refineries could supply CBG Type 1 (80 ppm sulfur) to Maricopa County in volumes sufficient to make up for shortfalls (if any) from the East refining center. (Gulf Coast refineries could also supply the other gasoline formulations and/or the diesel fuel formulations through the Longhorn pipeline, but not in volumes sufficient to meet Maricopa County demand.)

Rationale for the Timing Estimates

The lead times for introducing the fuel formulations of choice in Maricopa County are determined by the requirements for capital investment in the supply system.

- All but one of the gasoline formulations (**G1**) would call for investment in the West refining center, and all would call for investment in the East refining center.
- All but one of the diesel formulations (**D1)** would call for some capital investment in the refining sector (both West and East refining centers).
- The diesel formulations could call for some capital investment in the distribution system if the system chose to supply three (rather than two) grades of diesel fuel to Arizona.

In general, refinery investments called for by a new fuel standard are likely to require a lead time of *at least* two years in the East refining center and three or four years in the West refining center, measured from the investment trigger date. Pipeline investments (e.g., additional break-out tanks) are likely to require at least one year. Hence, the pace of refinery investments will determine when the fuel formulations of choice would be available.

Refiners could choose to undertake necessary capital investments as soon as the Arizona legislature puts a new program into state law – say, April 1998 – or as late as full approval of the new Arizona program by all parties (e.g., by EPA) – say, October 1999. These two alternatives define the range of availability dates given above.

Key Results and Findings: Fuel Distribution

Pipeline Throughput and Capacity

In 1997, the West and East pipeline systems delivered these volumes to the Phoenix area:

	Total Volume	% Shares	
	(K Bbl/day)	West	East
? Gasoline	82.6	70%	30%
? EPA diesel fuel (taxable and non-taxable)	27.4	88%	12%
? Off-road (high sulfur) diesel fuel	1.1	0	100%

At present, the West pipeline's Colton-to-Phoenix segment operates at about 95% of its capacity (≈ 175 M Bbl/day), on average, and at 100% capacity during certain periods. The East pipeline's Tucson-to-Phoenix segment operates at about 70% of its capacity (≈ 55 M Bbl/day).

Gasoline Supply

The distribution system has the capability to deliver required volumes of any of the proposed gasoline formulations (or other formulations, whether produced to property-based or performance-based standards) – even though these gasolines are not the same as those supplied to the rest of the state.

The difference between CBG (Maricopa County) and conventional (state-wide) gasoline standards leads to some spill-over and local give-away of "excess quality" in Maricopa County and adjoining areas. For any of the gasoline formulations considered, the spill-over volume and costs would be about the same as for baseline gasoline (i.e., with business-as-usual). That is, none of the gasoline formulations would lead to a significant increase in spill-over cost.

Diesel Fuel Supply

The West pipeline system – but not the East – has facilities in place to deliver CARB diesel fuel to the Phoenix, but not any of the other diesel fuel formulations. The other proposed diesel fuel formulations would constitute an additional grade in the distribution system. Handling an additional grade would call for some capital investment (e.g., additional tankage at refineries, along the pipeline, and/or at terminals). The investment and corresponding per-gallon capital charges would be the same for all the diesel fuel formulations, other than the CARB diesels.

Supplies of Diesel Fuel to Mining Areas

The prospect of new gasoline and diesel fuel formulations for Maricopa County has raised the concern that the new fuels might have adverse effects on the supply and cost of non-taxed (dyed) diesel fuel (high-sulfur or EPA) in rural and mining areas in Arizona.[3] The mining industry in particular now consumes 6K Bbl/day, about 60 % of which is high-sulfur diesel.

Our analysis indicates that the sources of gasoline and diesel fuel supply to Maricopa County are, for the most part, different than the sources of diesel fuel supply to the mining areas. In particular, about 70% of the gasoline and about 90% of the diesel fuel supplied to the Phoenix area comes from the West refining center. Certain refiners in the East refining center do not supply diesel fuel to Maricopa County. All high-sulfur diesel fuel supplied to mining areas comes from certain refineries in the East refining center. EPA diesel fuel supplied to the mining areas comes from the West, East, and Gulf Coast refining centers, in proportions that cannot be established readily.

New gasoline and diesel fuel formulations in Maricopa County are unlikely to have an important effect on the supply of non-taxable diesel fuel available to the mining areas. One or more East refineries might invest in upgrading some of their gasoline and/or diesel fuel output to meet

3 EPA diesel is more costly to produce and usually commands a premium of about 2 to 4¢/gal.

Maricopa County standards. But such investments, if made, would not reduce the overall output of non-taxable EPA and high-sulfur diesel fuel output available for supply to Arizona's mining areas. This finding is based on discussions with East refiners and is consistent with principles of refining economics.

New gasoline and diesel fuel formulations in Maricopa County could increase the cost of supplying non-taxed diesel fuel to the mining areas. The cost of supplying diesel fuel could increase as a consequence of (1) possible investments in the East pipeline system to handle a third grade of diesel fuel, (2) possible investments by bulk terminals in the Phoenix area to handle a third grade of diesel fuel, (3) a possible increase in the proportion of EPA diesel fuel in the non-taxed diesel fuel pool, and (4) an increase in the average cost of production in the refineries that supply Arizona. The combined magnitude of these cost effects is likely to be small on a per-gallon basis.

The cost effects would be felt by various market segments in Arizona. Forecasting the distribution of possible future costs is beyond the scope of this study.

As noted above, the advent of the Longhorn pipeline could both add to the availability of non-taxable diesel fuel supplies and lower the cost of supplying diesel fuel to Arizona. These possible effects of the Longhorn pipeline would not depend on the new gasoline and diesel fuel formulations of choice in Maricopa County.

Additional Considerations

- The estimated physical properties of the baseline gasoline indicate that gasoline supplied to Maricopa County under the CBG program from 1999 on will have better emission performance than gasoline supplied to Maricopa County prior to the advent of the CBG program – and in particular, the "assumed gasoline" used in the development of baseline emission inventories. A similar situation exists for diesel fuels. The State of Arizona may wish to estimate the magnitude of these increments of emission improvement and their effects on future emission inventories, and to reflect these effects in its planning.

  To account for differences in emissions quality between the fuels assumed in estimating Maricopa County baseline inventories and the baseline fuels used in this study, we subtracted (or added, as appropriate) the corresponding emissions differentials *prior to* evaluating individual fuel option benefits. Hence, these emission differentials are not included in the results shown in Exhibits ES-2, ES-3, and ES-4.

- Consistent with the SoW, we did not assess the effects of the various fuel formulations on the "brown cloud" phenomenon. For reasons of time, resources, and technical feasibility, *quantitative* assessment of effects on the "brown cloud" would not have been feasible.

However, *qualitative*, rank-order assessment of the fuel formulations with respect to their likely effects on the brown cloud is possible – through analysis of the PM impacts of the various fuel formulations.

The brown cloud phenomenon is not well understood. There is little doubt that the severity of the problem depends on the level of light-obscuring PM in the atmosphere. However, brown cloud formation also depends on factors such as meteorology, availability of secondary particulate nucleation sites, and quantity of "natural" light-scattering particles (e.g., water vapor) in the air. These conditions vary over both time and space, making it difficult to quantify improvement in the brown cloud phenomenon in response to any given reduction in PM emissions.

- The results of this study indicate little or no impact of the various gasoline and diesel fuel formulations on areas of Arizona outside of Maricopa County.

  In particular, our analysis of the refining sector included the premise that after adoption of a new Winter gasoline standard and/or a new diesel fuel standard for Maricopa County, refiners would produce Maricopa County gasoline and/or diesel fuel to the new standard(s) in a manner such that areas in Arizona outside Maricopa County would experience no decrease in the emissions performance of the gasoline and/or diesel fuel that they received.

- Through traffic (trips beginning and/or ending outside of Maricopa County) accounts for some (indeterminate) portion of the diesel vehicle miles traveled and the diesel fuel volumes sold and consumed in Maricopa County. The economics and the operating flexibility of the over-the-road trucking industry make it likely that the volume of diesel fuel purchased in Maricopa County would decrease with increasing end-use price of diesel fuel formulations (as over-the-road and short-haul truckers elected to purchase EPA diesel outside of Maricopa County). To the extent that this fueling shift occurs, it would affect sellers of diesel fuel in Maricopa County and would reduce the emission benefits of the diesel fuel formulations.

  This prospective fueling shift does not lend itself to quantitative analysis, because data on the distribution of diesel vehicle miles traveled (by vehicle category and type of travel) are not available.

  In the emissions analysis, we assumed that 15% of the vehicle miles traveled by heavy heavy duty diesel vehicles would be subject to a fueling shift from the Maricopa County diesel fuel formulation to EPA diesel fuel purchased outside Maricopa County. The emissions and cost-effectiveness estimates reflect this fueling shift.

- The California legislature is considering whether to curtail or terminate the use of MTBE as a gasoline blendstock in California. Without countervailing changes in state and federal regulations, such a move would adversely affect the gasoline-making capability of the California refining sector. It would increase the average cost of CARB RFG2 produced for in-state consumption and likely would reduce the refineries' overall gasoline out-turn. It could affect the cost, availability, and emission performance of CARB RFG2 (**G3** and **G4**) supplied to Maricopa County.

  The California Energy Commission is now conducting a study to examine the effects on the supply and price of CARB RFG2 of a possible ban on MTBE blending. Results of that study should be available by mid-1999. Results of a companion study, on the health effects of MTBE, should be available by the end of 1999.

- The advent of the proposed Longhorn Partners Pipeline would be unlikely to change the overall economics, cost-effectiveness, or (with the possible exception discussed above) the time of availability of the various gasoline and diesel fuel formulations.

  The Longhorn pipeline would carry refined products from the U.S. Gulf Coast to El Paso, where it would link to the SFPP East pipeline system. The pipeline could allow Gulf Coast refiners to deliver gasoline and/or diesel fuel to Maricopa County for 2-3☞/gal less than they could now.

  The volume of fuel supply from the U.S. Gulf Coast to Maricopa County via the Longhorn pipeline would be limited by the capacity of the SFPP East pipeline system (which now has about 20 M Bbl/day of spare capacity). Without an expansion of the

  SFPP East pipeline system, the Longhorn pipeline could not deliver enough fuel from the U.S. Gulf Coast to replace the volumes now supplied by the West refining center.

Technical Approach

The specified target years for the analysis are 1999, 2001, and 2010 for *CO* emissions and 1999, 2004, and 2010 for *VOC*, *NOx*, and *PM* emissions.

The analysis had three primary subjects:

1. The *gasoline and diesel fuel distribution system* serving Maricopa County, to identify possible effects of the distribution system on the cost, feasibility, and timeliness of implementation of the various gasoline and diesel fuel formulations;

2. The *refining sector*, to estimate (1) the costs of producing the various fuel formulations in the volumes required by Maricopa County, (2) the feasibility of producing the various fuel formulations in each of the target years, and (3) the physical properties of the various fuel formulations; and

3. Changes in *vehicle emissions and emission inventories* in Maricopa County, associated with each of the fuel formulation options in each of the target years.

We used the ARMS refinery modeling system to estimate the average incremental costs and physical properties of the five gasoline formulations. We modeled two refining aggregates:

- **East** (denoting refineries in the West Texas/New Mexico refining center, supplying Maricopa County via SFPP's East pipeline system)

- **West** (denoting the Los Angeles refining center plus one refinery each from the Bakersfield and San Francisco refining centers, supplying Maricopa County via SFPP's West pipeline system)

We combined the two sets of results to obtain average incremental refining costs and average properties for gasoline supplies to Maricopa County, consistent with the volume shares of West and East supplies to Maricopa County in 1997.

We estimated the average incremental costs and physical properties of the six diesel fuel formulations using published sources of information.

The emissions analysis used (1) the average properties of the baseline gasoline and the baseline diesel fuel and (2) the average properties of the various gasoline and diesel fuel options (drawn from the refining analysis).

The emissions analysis employed these models:

- The EPA Complex Model for certifying federal RFG
- The EPA Complex Model for CO
- The California Predictive Model for certifying CARB RFG
- The EPA MOBILE5a model for estimating vehicle fleet emissions of CO, VOC, and NOx,
- The EPA PART5 model for estimating PM emissions of the gasoline vehicle fleet
- An adaptation and extension, developed for this study, of the Sierra Research model for estimating vehicle emissions as functions of diesel fuel properties

The EPA Complex Model, MOBILE5a, and PART5 models and the California Predictive Model are established, peer-reviewed tools for analyses such as this one. The EPA Complex Model for

CO has received limited peer review and is not as well established for regulatory analysis as the other EPA models.

Uncertainty and Robustness

Even though the technical approach was comprehensive and rigorous (within the limits of time and resources), uncertainties abound: in the nature of the phenomena that we analyzed, the assumptions and the data available for the analysis, and the predictive capabilities of the available mathematical models. In particular, we note uncertainties in estimating (1) baseline emissions inventories, (2) on-road and off-road diesel fuel consumption in Maricopa County, (3) gasoline vehicle CO emissions and diesel vehicle emissions as functions of fuel properties, and (4) costs of the diesel fuel formulations. In addition, the study looks to the future: 1999 to 2010. There are no facts about the future.

Had more time been available, we could have reduced the uncertainties in our estimates of items (2) and (4) above, and we could have shed light on item (1). But, even with more time (and more resources), one could not eliminate all uncertainty, because certain phenomena – such as the brown cloud mechanisms and the effects of fuel properties on vehicle emissions – are simply not fully understood yet.

Consequently, one should have modest expectations about the precision of the results presented here and the likelihood that they "predict" future conditions. But one can – and should – view the results as reliable and robust indicators of the relative merits of the various fuel formulations, with respect to (1) the magnitude of their costs, benefits, and cost-effectiveness and (2) their rank order with respect to cost-effectiveness.

Analyses such as this one give consistent treatment to all the options under consideration and focus on comparative (or relative) results – similarities and differences between options – rather than on absolute results or forecasts. Experience shows that the important differences between options and the important (qualitative) characteristics of individual options usually survive changes in primary assumptions and eventual resolution of uncertainties.

Exhibit ES-1: Gasoline and Diesel Fuel Options Evaluated

► **Gasoline**

G1. CBG Type 1 (≈ Fed RFG2) with ≤ **80** ppm sulfur (season average)

G2. CBG Type 1 (≈ Fed RFG2) with ≤ **30** ppm sulfur (season average)

G3. CBG Type 2 (CARB RFG2) with **2.0** wt.% oxygen

G4. CBG Type 2 (CARB RFG2) with **3.5** wt.% oxygen

G5. CO Performance Standard Gasoline

► **Diesel Fuel**

D1. Baseline EPA Diesel, Cetane Enhanced (+ 5 cetane numbers)

D2. Baseline EPA Diesel, Cetane Enhanced and 100 ppm sulfur

D3. CARB Diesel – Formula Properties with 200 ppm sulfur

D4. CARB Diesel – Average Properties of Certified Alternative Formulations

D5. Advanced Blend (CARB diesel and Fischer-Tropsch distillate)

D6. Swedish Class 1 Diesel

Gasoline formulations **G1**, **G2**, **G4**, and **G5** are ethanol blended and contain 3.5 wt.% oxygen. Gasoline formulation **G3** is MTBE blended and contains 2.0 wt.% oxygen.

Exhibit ES-2: *Gasoline Formulations* -- Cost-Effectiveness; Refining and Mileage Costs; and CO, PM-10, and PM-2.5 Emission Reductions Winter Season

Measure	Total Baseline Emissions	~ Fed RFG2 with		CARB RFG2		CO
		80 ppm Sulfur (G1)	30 ppm Sulfur (G2)	2.0 wt % Oxygen (G3)	3.5 wt % Oxygen (G4)	Performance Standard (G5)
Cost-effectiveness ($K/mt CO)						
2001		18	9	30	9	8
2010		35	13	48	13	11
Refining & Mileage Cost (¢/gal)		**1.3**	**4.8**	**9.7**	**8.3**	**6.2**
Incremental Refining Cost		1.2	4.6	9.9	7.6	5.7
Fuel Economy Cost		0.1	0.2	-0.2	0.7	0.5
Refining Investment Required		Yes	Yes	Yes	Yes	Yes
Maricopa County Cost ($K/day)						
2001		46	171	345	295	220
2010		56	208	420	359	268
Emission Reductions (mt/day)						
CO						
2001	611	2.5	19.7	11.5	32.7	28.5
2010	575	1.6	16.6	8.8	28.3	24.5
PM-10 (total)						
2004	198	0.8	1.8	2.0	2.1	2.0
2010	208	0.9	2.0	2.2	2.3	2.2
PM-2.5 (total)						
2004	110	0.7	1.6	1.8	1.8	1.8
2010	112	0.8	1.8	2.0	2.0	1.9

Note: mt denotes metric tons.

Exhibit ES-3: *Diesel Formulations* -- Cost-Effectiveness; Refining and Mileage Costs; and PM-10, PM-2.5, NOx, VOC, and CO Emission Reductions
Winter Season

Measure	Total Baseline Emissions	EPA Diesel with Enhanced Cetane (D1)	EPA Diesel with 100 ppm S + Cet (D2)	CARB Diesel with Formula Properties (D3)	CARB Diesel with Average Properties (D4)	Advanced Diesel Blend (D5)	Swedish Class 1 Diesel (D6)
Cost-effectiveness ($K/mt)							
PM-10 (primary)							
2004		71	46	106	56	60	91
2010		66	41	98	51	55	83
Combination*							
2004		3	4	13	5	6	19
2010		3	4	14	5	6	19
Refining & Mileage Cost (¢/gal)		**1.5**	**2.5**	**12.4**	**5.1**	**8.9**	**35.4**
Incremental Refining Cost		1.5	2.0	10.0	4.0	6.0	32.0
Fuel Economy Cost			0.5	2.4	1.1	2.9	3.4
Refining Investment Required		No	Yes	Yes	Yes	Yes	Yes
Maricopa County Cost ($K/day)							
2004		15	25	125	51	89	356
2010		17	29	144	59	103	412
Emission Reductions (mt/day)							
PM-10 (primary)*							
2004	176	0.2	0.5	1.2	0.9	1.5	3.9
2010	184	0.3	0.7	1.5	1.2	1.9	4.9
PM-10 (total)*							
2004	204	0.3	1.1	1.4	1.4	2.3	5.2
2010	214	0.3	1.5	1.7	1.8	2.9	6.6
PM-2.5 (total)*							
2004	115	0.2	1.0	1.3	1.3	2.1	4.8
2010	117	0.3	1.4	1.6	1.7	2.7	6.2
NOx							
2004	271	1.1	1.7	4.9	3.8	6.2	8.5
2010	283	1.1	1.9	5.3	4.1	6.6	9.2
VOCs							
2004	234	2.7	2.6	2.2	4.3	5.6	4.1
2010	248	3.2	3.1	2.6	5.2	6.7	4.9
CO							
2004	611	5.2	5.2	5.5	9.2	12.7	7.2
2010	575	6.3	6.4	6.8	11.3	15.5	8.8
Combination*							
2004***	805	4.8	6.3	9.4	10.9	16.0	18.9
2010	827	5.5	7.4	10.6	12.6	18.4	21.9

Note: mt denotes metric tons.

* Combined emissions calculated as: PM-10 + NOx + VOCs + CO/7

** Annual average

*** Includes interpolation of CO emissions for 2004

Exhibit ES-4: *Diesel Formulations* -- Cost-Effectiveness; Refining and Mileage Costs; and PM-10, PM-2.5, NOx, VOC, and CO Emission Reductions
Summer Season

Measure	Total Baseline Emissions	EPA Diesel with: Enhanced Cetane (D1)	EPA Diesel with: 100 ppm S + 5 Cet (D2)	CARB Diesel with: Formula Properties (D3)	CARB Diesel with: Average Properties (D4)	Advanced Diesel Blend (D5)	Swedish Class 1 Diesel (D6)
Cost-effectiveness ($K/mt)							
PM-10 (primary)							
2010		71	45	106	55	59	90
Combination*							
1999		2	*2*	*7*	*3*	*3*	*11*
2010		2	2	8	3	3	12
Refining & Mileage Cost (¢/gal)		**1.5**	**2.5**	**12.4**	**5.1**	**8.9**	**35.4**
Incremental Refining Cost		1.5	2.0	10.0	4.0	6.0	32.0
Fuel Economy Cost			0.5	2.4	1.1	2.9	3.4
Refining Investment Required		No	Yes	Yes	Yes	Yes	Yes
Maricopa County Cost ($K/day)							
1999		14	*23*	*115*	*47*	*83*	*329*
2010		19	31	156	64	112	445
Emission Reductions (mt/day)							
PM-10 (primary)*							
2004	176	0.2	0.5	1.2	0.9	1.5	3.9
2010	184	0.3	0.7	1.5	1.2	1.9	4.9
PM-10 (total)*							
2004	204	0.3	1.1	1.4	1.4	2.3	5.2
2010	214	0.3	1.5	1.7	1.8	2.9	6.6
PM-2.5 (total)*							
2004	115	0.2	1.0	1.3	1.3	2.1	4.8
2010	117	0.3	1.4	1.6	1.7	2.7	6.2
NOx							
1999	332	1.8	3.0	8.5	6.5	10.6	14.6
2010	393	2.2	3.6	10.3	7.9	12.9	17.8
VOCs							
1999	330	4.4	4.3	3.6	7.1	9.3	6.8
2010	299	6.3	6.1	5.2	10.1	13.2	9.6
CO							
1999	1991	14.3	14.4	15.4	25.7	35.2	20.1
2010	2131	22.2	22.4	23.8	39.7	54.5	31.1
Combination**							
1999***	1151	8.5	10.5	15.7	18.7	27.1	29.5
2010	1211	11.9	14.4	20.6	25.5	36.7	38.5

Note: mt denotes metric tons;
italics indicates formulations that could not be implemented by 1999 because of investment requirements.
* Combined emissions calculated as: PM-10 + NOx + VOCs + CO/7
** Annual average
*** Incorporates PM-10 emission reductions estimated for 2004

INTRODUCTION

MathPro Inc. (prime contractor) and Energy & Environmental Analysis, Inc. (sub-contractor) are pleased to submit this report to the Arizona Department of Environmental Quality (ADEQ), as the final work product of Task 2 under Contract 97-0013AA (August 9, 1996). The Scope of Work (SoW) for this task is shown in **Appendix A**. We have prepared this report to support the work of the Clean Burning Fuels Subcommittee of the Arizona Governor's Air Quality Strategies Task Force (the Subcommittee).

The report lays out the methodology, results, and findings of our analysis of prospective gasoline and diesel formulations and standards. The gasoline and diesel fuel formulations are aimed at decreasing vehicle emissions of

- Carbon monoxide (CO) in the Winter season (November 1 to March 31); and
- Volatile organic matter (VOC), nitrogen oxides (NOx), and particulate matter (PM), year-round.

The report addresses six topics, each in its own section.

1. Proposed gasoline and diesel fuel formulations
2. Baseline gasoline and diesel fuel properties
3. The distribution system serving Maricopa County and other areas in Arizona
4. Refining analysis of the proposed gasoline and diesel fuel formulations
5. Emissions analysis of the proposed gasoline and diesel fuel standards
6. Assessment of the proposed gasoline and diesel fuel standards

The appendices present the Scope of Work for the study (A), tables showing detailed results of the refining analysis (B), and tables showing detailed results of the emissions analysis (C, D, E, F, and G).

This report makes frequent mention of [Ref. 1]: *Final Report: Assessment of Fuel Quality Options for Maricopa County*, MathPro Inc., November 7, 1996 (submitted to ADEQ). [Ref. 1] reports on the analysis conducted by MathPro Inc. and AIR, Inc. of the technical, economic, and emission implications of various Summer gasoline formulations for Maricopa County (August – November, 1996).

Many elements of the data and analysis discussed in [Ref. 1] are relevant to the present analysis of Winter gasoline formulations and of diesel fuel formulations. Therefore, for brevity and consistency, we from to time refer the reader to relevant portions [Ref. 1] rather than repeat that material here.

Tables mentioned in the text appear in the text near where they are first mentioned. **Exhibits** mentioned in the text appear in the appendices.

1. PROPOSED GASOLINE AND DIESEL FUEL FORMULATIONS

1.1 Emissions Standards

1.1.1 Property-Based and Performance-Based Standards

Arizona could implement new gasoline and diesel fuel programs with either property-based standards or performance-based standards.

- *Property-based* standards are expressed as a set of limits on measurable physical properties of the regulated fuel (gasoline or diesel fuel).

  -- Gasoline: RVP, sulfur content, oxygen content, distillation curve, etc.

  -- Diesel: aromatics content, sulfur content, cetane number, etc.

  Property-based standards are usually set to achieve target emissions reductions.

- *Performance-based* standards are expressed as a set of upper limits on computed vehicle emissions of various species of pollutants produced by the regulated fuel (gasoline or diesel fuel) in specified vehicle types or engine types.

  -- Gasoline: CO, VOC, NOx, PM_{10}, etc.

  -- Diesel: PM (PM_{10} and/or $PM_{2.5}$), VOC, NOx, SOx, etc.

Property-based and performance-based standards can be imposed in either of two ways:

- *per-gallon*: <u>each</u> gallon must meet the standard, or
- *averaging*: the average gallon must meet the standard, either year-round or within a given season.

Averaging standards may be (and usually are) set in conjunction with per-gallon caps on fuel properties that must be met along with the performance averages.

With respect to gasoline standards, the federal Phase 1 RFG program began with a property-based standard, but shifted to a hybrid property- and performance-based standard in 1998. The federal Phase 2 RFG program (Fed RFG2) incorporates a hybrid standard (mostly performance-based). The California Phase 2 RFG program (CARB RFG2) incorporates both kinds of standard, and allows refiners to choose between them.

Arizona's Cleaner Burning Gasoline (CBG) program embodies performance-based standards, because it is linked to federal RFG (Fed RFG2, starting in May 1999)[1] and CARB RFG2.

With respect to diesel fuel standards, the federal on-road diesel standard (EPA diesel) is property-based (sulfur content $\leq$ 0.05 wt.%, aromatics content $\leq$ 35 vol.% or cetane index $\geq$ 40). The California diesel fuel program (CARB diesel) allows refiners to choose between a property-based standard (sulfur content $\leq$ 0.05 wt.%, aromatics content $\leq$ 10 vol.%) and a performance-based standard. The performance-based standard allows for certification of alternative formulations (with higher aromatics content) that demonstrate emissions performance for NOx, PM, and SOF (soluble organic fraction) equal to or better than that of the reference diesel fuel (with 10 vol.% aromatics) in a specified test engine.

Arizona's existing diesel fuel program – which requires EPA diesel for all uses in Maricopa County and for on-road use in the rest of the state – embodies property-based standards.

1.2 Some Additional Considerations

Property-based standards are simpler to design and enforce, because they are based on measurable fuel properties. They can be enforced simply, by sampling at the retail level.

Performance-based standards are more complicated. They require standard test procedures or mathematical models for certifying the emissions performance of individual batches of fuel produced and delivered. Downstream of the refinery, enforcement is complicated for an area such as Maricopa County, which receives fuel produced in out-of-state refineries and perhaps commingled in the distribution system before reaching the state. Downstream enforcement may, in practice, be limited to sampling at the retail level to verify compliance with the per-gallon caps on fuel properties associated with the performance-based standard.

However, performance-based standards allow the refining and distribution systems some flexibility in meeting a given level of emissions performance. Flexibility can translate into (1) lower refining costs than property-based standards, for any target level of emission reduction, (2) reduced impacts on refining costs of changes in market conditions, and (3) a larger pool of prospective suppliers in a given market, such as Maricopa County.

One can map any property-based standard into a corresponding performance-based standard, by setting emission performance targets to match the estimated or certified performance of the property-based standard.

1 Arizona's CBG Type 1 gasoline is essentially Fed RFG2, except that it involves no benzene content or toxic emission standards, and it has an EPA waiver for RVP $\leq$ 9.0 psi.

1.3 Gasoline and Diesel Fuel Formulations Evaluated

Table 1.1 (below) shows the gasoline and diesel fuel formulations evaluated in this study.

Sections 1.3.1 and 1.3.2 , respectively, provide brief descriptions of the gasoline and diesel fuel options. In this discussion, we often identify the fuel formulations by the codes in Table 1.1 (e.g., G1, D4, etc.).

Table 1.1: Gasoline and Diesel Fuel Formulations

- **Gasoline**

G1: CBG Type 1 (≈ Fed RFG2) with ≤ **80** ppm Sulfur (season average)

G2: CBG Type 1 (≈ Fed RFG2) with ≤ **30** ppm Sulfur (season average)

G3: CBG Type 2 (CARB RFG2) with **2.0** wt.% Oxygen

G4: CBG Type 2 (CARB RFG2) with **3.5** wt.% Oxygen

G5: CO Performance Standard Gasoline

- **Diesel Fuel**

D1: Baseline EPA Diesel, Cetane Enhanced (+ **5** cetane numbers)

D2: Baseline EPA Diesel, Cetane Enhanced and ≤ **100** ppm Sulfur

D3: CARB Diesel – Formula Properties with ≤ **200** ppm Sulfur

D4: CARB Diesel – Average Properties of Certified Alternative Formulations

D5: Advanced Blend (CARB diesel and Fischer-Tropsch distillate)

D6: Swedish Class 1 Diesel

1.3.1 Gasoline Formulations

All of the gasoline options are oxygenated. G1, G2, G4, and G5 are ethanol blended and contain 3.5 wt.% oxygen. G5 is MTBE blended and contains 2.0 wt.% oxygen.

*G1: CBG Type 1 (» Fed RFG2) with ≤ **80** ppm Sulfur (season average)*

This formulation extends and tightens the CBG Type 1 standard to include explicit sulfur control – in particular, a limit of *80 ppm* on *average* sulfur content.

As we define this gasoline formulation, the 80 ppm limit on sulfur content would be a volume-weighted average over an entire Winter season, applying separately to each individual refiner supplying gasoline to Maricopa County in that season.

*G2: CBG Type 1 (» Fed RFG2) with ≤ **30** ppm Sulfur (season average)*

This formulation also extends and tightens the CBG Type 1 standard to include explicit sulfur control – in this instance, a limit of *30 ppm* on *average* sulfur content.

As with the **G1** formulation, the 30 ppm limit on sulfur content would be a volume-weighted average over an entire Winter season, applying separately to each individual refiner supplying gasoline to Maricopa County in that season.

The 30 ppm limit on sulfur content conforms to CARB RFG2's sulfur limit under the averaging option. Arizona might wish to modify the definition of this formulation option, by adjusting the sulfur limit and/or instituting a per-gallon standard.

G3: CBG Type 2 (CARB RFG2) with 2.0 wt.% Oxygen

This formulation is the CARB RFG2 standard (property-based and performance-based options) for the Winter season.

As we define the **G3** formulation, it would be CARB RFG2 complying with the existing Maricopa County standard for RVP (≤ 9.0 psi). It would contain not more 2.1 wt.% oxygen (with averaging); refinery-blended MTBE would be the oxygenate. This formulation would entail a special Arizona version of the California certification process (to handle the Maricopa County RVP in the CARB Predictive Model).

G4: CBG Type 2 (CARB RFG2) with 3.5 wt.% Oxygen

This formulation is a variant of the CARB RFG2 standard, complying with the existing Maricopa County standard for oxygen content in Winter gasoline.

As we define the **G4** formulation, it would be CARB RFG2 complying with Maricopa County's region's existing standard for RVP ($\leq$ 9.0 psi). It would contain up to 3.5 wt.% oxygen; terminal-blended ethanol would be the oxygenate. This formulation also would entail a special Arizona version of the California certification process (to handle the Maricopa County limit on oxygen content in the CARB Predictive Model).

G5: CO Performance Standard Gasoline

This formulation is designed explicitly to reduce CO emissions by an amount roughly intermediate to the CO emission reductions of **G2** and **G4.** NOx and other emissions of CO Performance Standard Gasoline would be unconstrained.

For purposes of analyzing this gasoline formulation, we assumed that **G4** complies with the CARB property-based standards, for all gasoline properties except RVP and oxygen content – which comply with the Arizona CBG Winter standards.

1.3.2 Diesel Fuel Formulations

D1: Baseline EPA Diesel, Cetane Enhanced (+ 5 cetane numbers)

This fuel formulation is an EPA diesel fuel with cetane number five numbers higher than the cetane number of the baseline diesel fuel (defined in Section 2.2), with no change in any other baseline property. The latter requirement dictates that all of the cetane number increase be achieved through use of a cetane enhancer (that is, an additive, such as ethyl hexyl nitrate).

For purposes of this analysis, this diesel fuel option would have a cetane number of 48.

The baseline diesel fuel is, of course, an artifact of this analysis. Its properties represent the average diesel fuel barrel now being supplied to Maricopa County, but not necessarily any one real diesel fuel formulation. Accordingly, in practice, this option would be expressed as a property-based standard, with the cetane number specified to reflect (1) the average clear (i.e., additive-free) cetane number of the Maricopa County diesel pool for some reference time period and (2) the practical upper limit – about 5 numbers – on the cetane number boost obtainable solely with cetane enhancers.

D2: Baseline EPA Diesel, Cetane Enhanced and $\leq$ 100 ppm Sulfur

This fuel formulation is a special variant of EPA diesel fuel with (1) cetane number five numbers higher than the cetane number of the baseline diesel fuel (as with **D1**) and (2) sulfur controlled to $\leq$ 100 ppm. It would be produced through (1) use of a cetane enhancer and (2) hydrotreating to reduce sulfur to the controlled level.

D3: CARB Diesel - Formula Properties with 200 ppm sulfur

This option calls for CARB diesel fuel conforming to the CARB formula (i.e., property-based) standard, in all respects except sulfur content [Ref. 6]:

- Sulfur content $\leq$ 200 ppm
- Aromatics content $\leq$ 10 vol.%
- Polynuclear aromatics content $\leq$ 1.4 vol.%
- Cetane number (clear) $\geq$ 48

The CARB diesel formula limits sulfur content to 500 ppm . By contrast, the sulfur content of this diesel fuel formulation is 200 ppm. Hence, this formulation has better emissions performance than CARB diesel fuel blended strictly to the formula.

California refineries now produce EPA diesel fuel with an average sulfur content of 200 ppm [Ref. 4] – lower than the formula limit on sulfur content. These refineries would likely upgrade some of what is now EPA diesel out-turn to produce incremental CARB diesel out-turn, if Maricopa County specified this formulation. Upgrading would be unlikely to increase the sulfur content of the diesel fuel.

The CARB property-based standard is stringent and expensive to meet. Most California refiners have elected not to produce CARB diesel to the property-based standard, but rather to the performance-based standard (discussed below).

D4: CARB Diesel - Average Properties of Certified Alternative Formulations

This option calls for CARB diesel fuel conforming to the CARB performance-based standard. This standard involves certification of the emissions performance of alternative diesel formulations. Certification of an alternative formulation denotes that it has emissions performance equal to or better than the reference (formula) CARB diesel fuel in a specified (heavy-duty) test engine.

At least twenty-five different diesel formulations have been certified to date. Few of the certified formulations are in the public domain. But from [Ref. 4], one can infer that most of them involve lower sulfur levels and higher aromatics levels than the property-based standard.

For evaluating costs and emissions effects, we characterized this option in terms of the *average properties of CARB diesel* produced by the California refineries in 1996, as reported in [Ref. 3].

In principle, the **D3** and **D4** formulations should offer the same emissions benefits. However, estimates of emissions for the two need not be the same because we used (1) average properties reported in [Ref. 4] (which may not correspond to any given alternative formulation) for **D4** and (2) a computer-based model (described in Section 5) – not a test engine – to estimate emissions.

D5: Advanced Blend (CARB diesel and Fischer-Tropsch distillate)

This diesel fuel formulation is intended to be a performance-based standard, even though we define it as a blend of two diesel fuel materials: **D4** and an ultra-high-quality diesel blendstock called *Fischer-Tropsch (F-T) distillate* or *GTL distillate.* In particular, we considered a 2/1 blend of **D4** and F-T distillate.

This blend would have low sulfur and aromatics content, low specific gravity, and high cetane number – all desirable properties. F-T distillate contains no measurable sulfur or aromatics, and it has a cetane number of 75-80.

The Fischer-Tropsch process is a means of producing various refinery blendstocks from natural gas. In one form or another, Fischer-Tropsch technology has been in commercial use for nearly seventy years. Commercial F-T plants are in operation now, but none in the U.S. A number of major refining companies have or are developing proprietary F-T processes, and several have large-scale pilot plants in the U.S. Commercial volumes of F-T distillate produced in Malasia have been delivered to California, for use in blending CARB diesel fuel.

This option may or may not be available by 2000 or 2001. But it could well be available by 2004. One small commercial plant could supply enough F-T distillate to produce all of the **D5** needed to meet Maricopa County's entire diesel fuel demand.

D6: Swedish Class 1 Diesel

This option involves a property-based standard corresponding to that of Swedish Class 1 diesel fuel, which includes:

- Sulfur content $\leq$ 10 ppm
- Aromatics content $\leq$ 5 vol.%
- Cetane number $\geq$ 50
- Specific gravity $\leq$ 0.822

Swedish Class 1 diesel fuel is in commercial use, in relatively small volumes, in urban areas of Sweden. Designed to be an ultra-low-emission fuel, it may be the current extreme of commercial diesel fuel formulations in terms of emissions benefits. It is the extreme of diesel fuel formulations in terms of production cost.

1.4 Using CARB-Specified Fuels in Maricopa County

The California RFG2 and diesel fuel programs have standing in California, but not in other states. In California, "CARB RFG2" denotes a year-round emissions reduction *program*, including certification procedures, enforcement, etc. In the Arizona CBG program, "CARB RFG2" simply denotes a class of low-emissions gasoline formulations, with individual batches certified via the California Predictive Model but otherwise not subject to the California program.

Similarly, in Arizona, “CARB diesel” would denote a class of low-emissions diesel fuel formulations (formula blend and/or certified formulations), with individual batches certified using the CARB formula or certification procedure. As discussed in Section 1.3.2, the **D3** diesel fuel would have emissions performance superior to that of formula-blended CARB diesel.

2. BASELINE GASOLINE AND DIESEL FUEL PROPERTIES

The baseline fuels are real or notional fuels whose properties are the standard of comparison for estimating incremental supply costs, emission reductions, and cost-effectiveness ratios for the fuel options under consideration.

2.1 Baseline Fuel Properties

Tables 2.1 and **2.2 (**next page) show our estimates of the relevant baseline properties for gasoline and diesel fuel.

Sections 2.2, 2.3, and 2.4, respectively, delineate the basic premises, data sources, and methodology used in developing these baseline properties.

2.2 Basic Premises

The baseline gasoline and diesel fuel for the analysis reflect "business-as-usual" in Maricopa County, starting with the 1999 Summer season. That is, the baseline fuels are consistent with

- The *gasoline standards* in place for the 1999-2000 Winter season: Arizona Cleaner Burning Gasolines, CBG Type 1 and CBG Type 2;
- The *diesel fuel standards* in place now: EPA diesel, for on-road and off-road use; and
- The *current pattern of fuel supply* to Maricopa County from the two main sources – the Los Angeles refineries (via the Santa Fe Pacific Pipeline (SFPP) West pipeline system from Los Angeles through Colton) and the West Texas/New Mexico refineries (via SFPP's East pipeline system through El Paso and Tucson).

(The configuration of the SFPP pipeline systems and the current pattern of fuel supply are discussed in Section 3.)

"Current pattern of fuel supply" denotes (1) the current West and East shares of total gasoline and diesel fuel volumes delivered to Maricopa County – not necessarily the volume shares of any given refiner or marketer – and (2) the current predominance of CBG Type 1 in the Maricopa County market.

In establishing baseline fuel properties, we assumed no significant change between now and 1999 in the relative volumes (and individual refiners' shares) of West and East supplies. Likewise, we assumed that – with business as usual – most of the gasoline supplied to Maricopa

Table 2.1: Estimated Baseline Properties for Winter Gasoline

Property	Units	Value
RVP	psi	**9.0**
Oxygen content	wt.%	**3.5**
Sulfur content	ppm	**120**
Aromatics content	vol.%	**28.3**
Benzene content	vol.%	**1.2**
Olefins content	vol.%	**8.7**
E200	vol.%	**49.6**
E300	vol.%	**82.1**
Energy density	MM BTU/ Bbl	**5.049**

Table 2.2: Estimated Baseline Properties for Winter Diesel Fuel

Property	Units	Value
Sulfur content	ppm	**210**
Aromatics content	vol.%	**29.1**
Cetane number	---	**42.9**
Specific gravity	---	**0.856**
API gravity	^{o} API	**33.8**
T_{10}	^{o} F	**446**
T_{50}	^{o} F	**525**
T_{90}	^{o} F	**611**
Energy density	MM BTU/ Bbl	**5.46**

County would be CBG Type 1 gasoline (rather than CBG Type 2) in 1999 and later years, because CBG Type 1 is less costly to produce in most refineries.

We selected 1999 as the baseline period for two reasons.

First, the 1999-2000 Winter season will be the first "steady-state" Winter season in the Arizona CBG program. The 1997-1998 and 1998-1999 Winter seasons are transient seasons, each having gasoline standards that apply only for the one year.

Second, standards for Maricopa County gasoline and diesel fuel, from 1999 onward, are already in place. For the Subcommittee, these standards are "givens". The only choices open to the Subcommittee are prospective new standards, that would supersede the existing ones and contribute additional emissions reductions sometime after 1999.

2.3 Data Sources

Specifying baseline fuel properties is not straightforward because little data exists on the current properties of the gasoline and diesel fuel pools in Maricopa County. The best available sources of data on fuel quality are:

- The 1996 and 1997 semi-annual surveys of gasoline and diesel fuel quality conducted by the American Automobile Manufacturers Association (AAMA) [Refs. 2 and 3]
- The July 1997 report of the American Petroleum Institute and National Petroleum Refiners Association (API/NPRA) [Ref. 4]

The AAMA surveys deal with fuel samples drawn at the retail level in given areas (e.g., Phoenix). The samples are not tied to refinery sources, and the reported average fuel properties in the given areas are not volume-weighted.

The API/NPRA survey shows (in part) pool average properties for conventional gasoline and EPA diesel produced in the California refineries (including but not limited to the Los Angeles refineries) in the 1996 Summer season. The survey does not indicate the properties of gasoline and diesel fuel shipped to Maricopa County, and it offers no direct information on the gasoline and diesel fuel produced in the West Texas/New Mexico refineries.

2.4 Methodology

2.4.1 Gasoline

Under the business-as-usual premise, the gasoline supplied to Maricopa County in the 1999-2000 Winter season would be Arizona CBG Type 1, but with a lower sulfur content than the federal RFG2 standard calls for. It is reasonable to assume that this variant of CBG Type 1 will capture the market in 1999-2000 Winter at the expense of CBG Type 2, because Type 1 has a lower average refining cost in most refinery settings.

Our methodology for estimating baseline gasoline properties relies on the AAMA 1997 survey of Winter gasoline quality [Ref. 3] – except for sulfur content, for which we employed a special methodology. We devoted special attention to estimating sulfur content, because it is the most important determinant of CO and NOx emissions (after oxygen content, which is effectively fixed at 3.5 wt.% in the Winter season).

Properties Other Than Sulfur Content

The AAMA gasoline surveys provide information on the properties of gasoline samples at the retail level in various locales, including Phoenix. But they indicate neither the sources – by refinery or by refining complex (West or East) – of the various samples nor the retail gasoline volumes corresponding to the various samples.

Except for sulfur content, we used the AAMA Winter gasoline surveys to compute average properties (not volume-weighted) for the Maricopa County gasoline pools in 1996 and 1997 Winter months. The pool average properties for 1997 are the baseline gasoline properties that appear in Table 2.1 (again, except for sulfur content).

Strictly speaking, these (pool average) gasoline properties define a gasoline pool that complies with standards applicable in the 1996-1997 Winter season – not necessarily with the CBG standards for the 1999-2000 Winter season. But as it happens, the properties shown in Table 2.1 conform to the CBG Type 1 standard, with ethanol as the oxygenate.

Hence, we concluded that the baseline properties shown in Table 2.1 are a reasonable representation of CBG Type 1 gasoline likely to be supplied to Maricopa County in the 1999-2000 Winter season.

(Recognize that this last statement does not imply that every refinery now supplying gasoline to Maricopa County is necessarily supplying CBG Type 1 gasoline. But *on average*, the gasoline supplied to Maricopa County in the last Winter season seems to have met that standard.)

Sulfur Content

With respect to sulfur content, we used a methodology that did not rely on the AAMA gasoline surveys. The AAMA results are not volume-weighted; all gasoline samples have equal weight in the calculation of average gasoline properties for a given area. Furthermore, commingling in the distribution system precludes linking individual gasoline samples to specific refineries. This limitation is important, because gasoline supplied by the California refineries has much lower average sulfur content than that supplied by the West Texas/New Mexico refineries.

As noted above, Maricopa County's gasoline supplies come from two sources: California refineries via the West pipeline system and West Texas/New Mexico refineries via the East pipeline system. The volume shares, on an annual basis, are ≈ 70% West/30% East. In general, the average sulfur content of West gasoline is lower than that of East gasoline. These two factors are relevant to the definition of the baseline gasoline, but they are not reflected in the average gasoline properties shown in the AAMA survey.

Since the last AAMA Winter survey (January 1997), the Arizona Cleaner Burning Gasoline (CBG) program has taken effect, introducing standards that influence the sulfur content of Maricopa County gasoline. The Complex Model became the required means of certifying batches of federal RFG (i.e., CBG Type 1), as of January 1998. CBG Type 1 gasoline must conform to federal RFG2 emission standards for VOC and NOx emissions in 1999.

These regulatory changes are likely to trigger some reduction in the average sulfur content of Maricopa County gasoline supplies between January 1997 and the 1999-2000 Winter season (the baseline period). In particular, the average sulfur content of *East* gasoline supplies is likely to decrease by the 1999-2000 Winter season, as each individual East refiner comes into compliance with the CBG program and the Fed RFG2 standards. The average sulfur content of West gasoline supplies need not change for compliance with the CBG program.

Our methodology for estimating the sulfur content of the baseline gasoline (1) accounted for changes in gasoline sulfur content likely to be induced by regulatory changes between January 1997 and the 1999-2000 Winter season and (2) relied on data drawn from the Arizona Gasoline Quality Monitoring (AGQM) reports submitted monthly by individual refineries in 1996.

The AGQM reports were submitted to ADEQ by the refiners producing gasoline to Maricopa County standards in 1996.[2] The confidential monthly reports showed the relevant properties (measured at the refinery) of each gasoline batch produced to Maricopa County standards. (Some of the reported batches may have been shipped to other markets or sold at retail under

2 The AGQM reports for the 1996 Summer season are discussed more fully in MathPro Inc.'s report to ADEQ, *Assessment of Fuel Quality Options for Maricopa County*, November 1996 [Ref. 5]. This report was prepared in support of the Fuels Subcommittee of the Arizona Air Quality Strategies Task Force, which was considering gasoline options for the Summer season.

different brands.). Thus, the differences in sulfur content by refiner and by refining center are reflected in the AGQM reports.

The AGQM reports for July, August, and September 1996 indicate the following information regarding Maricopa County's gasoline supplies in the 1996 Summer season.

- Volume shares: 74% West/26% East
- Average sulfur content: 88 ppm West/353 ppm East (approx.)

Our methodology for estimating the sulfur content of baseline gasoline comprised these steps:

1. Set the average sulfur content of *West* gasoline supplies in the baseline period at 90 ppm (essentially unchanged from the 1996 Summer season).

2. Set the average sulfur content of *East* gasoline supplies in the baseline period at 225 ppm.

   We arrived at this estimate by applying the EPA Complex Model, using the average properties of East gasoline supplies derived from the AGQM reports.

3. Take the volume-weighted average of the average sulfur levels of the West and East supplies, using as weights the volume shares listed above.

This methodology produced the estimate of 120 ppm shown in Table 2.1 for the sulfur content of the baseline gasoline.

2.4.2 Diesel Fuel

For diesel fuel, we assumed that the on-road diesel fuel supplied to Maricopa County in the 1999-2000 Winter season would have – under the business-as-usual premise – average properties similar to those of the on-road diesel fuel supplied to Maricopa County in 1997.

One cannot estimate directly the average properties of the on-road diesel fuel supplied to Maricopa County in 1997. The AAMA surveys on diesel fuel properties do not cover Phoenix, and (as noted in Section 2.3) the API/NPRA survey does not indicate the properties of gasoline and diesel fuel shipped to Maricopa County.

We used an indirect approach, based on the available data and involving three steps.

1. Set the average properties of EPA diesel fuel supplied via the West pipeline system in 1997 equal to the average properties of EPA diesel fuel produced in the California refineries in the 1996 Summer season, as reported in [Ref. 4].

2. Set the average properties of the EPA diesel fuel supplied via the East pipeline system in 1997 equal to the average properties of EPA diesel fuel supplied to Albuquerque in the 1996 and 1997 Summer and Winter seasons, as reported in [Ref. 3]. Albuquerque's EPA diesel fuel is likely to be similar to EPA diesel fuel supplied to Maricopa County's via the East pipeline system, because West Texas refineries account for a large portion of Albuquerque's refined product supply.

3. Calculate the volume-weighted average of the two sets of EPA diesel properties, with weightings corresponding to the shares of EPA diesel supplied to Maricopa County in 1996, via the West and East pipeline systems, as reported by the pipeline company. For 1996, the reported shares for EPA diesel were 92% West and 8% East.

4. Calculate the energy density of the baseline diesel fuel using the method outlined in Section 4.2.3.

This methodology produced the baseline diesel fuel properties shown in Table 2.2.

3. THE FUEL DISTRIBUTION SYSTEM SERVING MARICOPA COUNTY

This section deals with the distribution of gasoline and diesel fuel to Maricopa County and the supply of diesel fuel to certain areas outside Maricopa County. It has four parts.

1. Current and projected gasoline and diesel fuel consumption in Maricopa County
2. Current pipeline deliveries of gasoline and diesel fuel to Phoenix and Tucson.
3. Spillover associated with new winter gasoline formulations
4. Supply of diesel fuel to Arizona

[Ref. 1, Section 3] provides an extensive discussion of the configuration and economics of the SFPP West and East product pipeline systems serving Maricopa County. Interested readers will find there a description of the pipeline system.

3.1 Gasoline and Diesel Fuel Consumption in Maricopa County

Table 3.1 shows estimated consumption of gasoline and diesel fuel in 1997, in Arizona and Maricopa County, by season.

Statewide gasoline consumption in 1997 averaged about 138 K Bbl/day. This is about a 6% increase from estimated average consumption in 1995 (the last full year for which we had data in the previous study). Maricopa County's gasoline consumption averaged about 77 K barrels/day (about 56% of statewide consumption), about a 9½% increase from estimated average consumption in 1995. About 16% of gasoline sales is premium grade. The remainder is mostly regular grade.

Statewide consumption of *on-road* diesel fuel averaged about 45 K Bbl/day in 1997, about a third of gasoline consumption. Unfortunately, Arizona does not collect diesel fuel sales by county, nor does it allocate aggregate diesel fuel sales by county to reflect either sales (where the sales outlet is located) or use (where the diesel fuel is consumed).[3]

We estimated diesel fuel consumed in Maricopa County using estimates of on-road, diesel-related VMT (vehicle miles traveled), average miles per gallon for diesel-fueled vehicles, and off-road diesel fuel consumption. We developed estimates of on-road diesel VMT from information provided by Arizona's Department of Transportation on VMT by vehicle class and roadway. (These data are reported to the FHWA and EPA and serve as the basis for various

3 In cost and cost-effectiveness calculations presented to the Subcommittee on January 26, 1998, we relied on a spreadsheet provided by Arizona's Department of Transportation that apparently showed diesel fuel ("use fuel") sales allocated by county. We later learned that the aggregate numbers for diesel fuel reflect estimates of the use (not sales) of taxed (on-road) diesel fuel, and that the county allocations are based on an arcane revenue-sharing formula, and are not related to sales or use by geographic location. The county allocations are not useful for this study's purposes, and we did not use them in preparing this final report.

federal publications and environmental determinations.) We used an estimate of 8.9 miles/gallon to translate daily VMT to daily, on-road fuel consumption. Finally, we used factors from the emissions modeling (Section 5) to estimate off-road diesel fuel consumption. We estimate off-road diesel fuel consumption to be about one third of on-road consumption. Our calculations suggest that Maricopa County's diesel fuel consumption in 1997 was about 23 K barrels/day.

Table 3.1 shows projected gasoline and diesel fuel consumption for Maricopa County to the year 2010. (We used these projections in calculating aggregate costs and cost-effectiveness of the various fuel formulations in target years of interest.) The projections of fuel consumption are based on projections of VMT growth, gasoline/diesel VMT splits, and fuel economy – these same factors are used in the emissions modeling. Hence, the fuel use and emissions estimates are made using a common set of assumptions regarding future growth in fuel demand and changes in fuel economy.

Table 3.1: Estimated Current and Projected Consumption of Gasoline and Diesel Fuel in Arizona and Maricopa County, by Season
(barrels/day)

	Gasoline			Diesel		
	Summer	**Winter**	**Average**	**Summer**	**Winter**	**Average**
Arizona - 1997	140,600	136,000	138,300	46,500	43,000	44,800
Maricopa County						
1997	77,300	76,400	76,900	24,100	22,300	23,200
1999*	81,500	80,600	81,100	26,000	24,100	25,100
2001*	85,600	84,600	85,100	27,600	25,600	26,600
2004*	91,700	90,600	91,100	30,400	28,200	29,300
2010*	104,200	103,000	103,600	35,200	32,600	33,900

Source: Arizona Department of Transportation
* Derived using projected VMT, VMT splits betweeen gasoline and diesel, and fuel economy.
Note: Diesel consumption for Arizona includes only taxed (on-road) diesel fuel.
Estimated diesel fuel consumption for Maricopa County includes both on-and off-road consumption.

3.2 The Pipeline Systems Serving Maricopa County

Two refined product pipelines serve Phoenix and Tucson, both owned and operated by Santa Fe Pacific Pipeline Partners, L.P (SFPP). The West line moves refined products from the Los Angeles basin to Phoenix and on to Tucson. The East line moves refined products from El Paso to Tucson and on to Phoenix.

For purposes of this analysis, one may view the West pipeline as a high capacity line (24" and then 20") from Watson (in the Los Angeles Basin) to Phoenix, with a smaller (6") line from Phoenix to Tucson. The East line is a 12" and 8" looped line from El Paso to Tucson, with a smaller 8" line from Tucson to Phoenix. By virtue of this configuration, both Phoenix and Tucson are served by both West and East refineries.

At Colton (in Southern California, near San Bernardino), the West line has a connection with the Cal-Nev pipeline, which carries refined products (produced in the Los Angeles refining center) on to the Las Vegas market area. (Las Vegas gasoline is subject to standards that are essentially the same as Arizona's state-wide standards.)

In a letter to us (dated September 26, 1996), SFPP stated that

> "… the West line generally does not operate at full capacity. In the past several years, [the West line's segment between SFPP's Watson Station (in the Los Angeles Basin and Colton terminal] has operated at capacity for limited periods due to unusual circumstances and seasonal transitions. Unusual circumstances include instances when [refiners in the East group] have experienced operational difficulties and requested unusually large volumes be moved to Phoenix and/Tucson from the Los Angeles area. Seasonal transitional periods (especially the spring transition to low RVP [gasoline]) result in customers drawing down their inventories to turn the tanks to the new specification. After the tanks are turned, unusually large volumes may be moved in a brief period to replenish inventories.
>
> In the past several years, the [East] pipeline has not operated at capacity."

Tables 3.2 and **3.3** show the average daily volumes of gasoline and diesel fuel delivered in 1997 by the West and East lines to Phoenix and Tucson terminals.

About 70% of the gasoline supplied to Phoenix comes through the West line; the remaining 30% through the East line. About 92% of gasoline moved through the West line goes to Phoenix, with the remaining 8% going to Tucson. About 54% of gasoline moved through the East line goes to Phoenix. Roughly the same pattern of gasoline deliveries occurred in 1995, the year examined in our previous report.

Table 3.2: Pipeline Deliveries of Gasoline to Phoenix & Tucson, by Grade and Pipeline, 1997
(barrels/day)

Product/ Delivery Area	Pipeline		Total
	West	East	
Phoenix	**62,300**	**26,200**	**88,500**
Premium	11,500	2,600	14,000
Regular	50,800	23,700	74,500
Tucson	**4,900**	**22,300**	**27,100**
Premium	900	3,400	4,300
Regular	4,000	18,900	22,800
Phoenix & Tucson	**67,200**	**48,500**	**115,700**
Premium	12,400	5,900	18,300
Regular	54,800	42,500	97,300

Source: "Trunk Line Product Recap Report," Santa Fe pacific Pipeline Partners, L.P., Products Movement Department, December, 1997.

Table 3.3: Pipeline Deliveries of Diesel Fuel to Phoenix & Tucson, by Type and Pipeline, 1997
(barrels/day)

Destination	Type of Diesel Fuel			Total
	Hi-sulfur	EPA	CARB	
Phoenix	**1,100**	**27,400**	**0**	**28,500**
West 24"	-	24,200	0	24,200
El Paso 12"	1,100	3,200	-	4,300
Tucson	**3,000**	**5,900**	**0**	**8,900**
West 24"	-	2,300	-	2,300
El Paso 8"	200	700	-	900
El Paso 12"	2,900	2,900	-	5,800
Phoenix & Tucson	**4,100**	**33,300**	**0**	**37,400**

Source: "Trunk Line Product Recap Report," Santa Fe pacific Pipeline Partners, L.P., Products Movement Department, December, 1997.

About 85% of the diesel fuel supplied to Phoenix comes through the West pipeline. Further, the West pipeline delivers virtually all EPA diesel. As with gasoline, about 91% of diesel fuel moved through the West pipeline goes to Phoenix, the remaining 9% going to Tucson. About 40% of diesel fuel moved through the East pipeline goes to Phoenix. About ¼ of the small volume of diesel fuel supplied to Phoenix by the East pipeline is high-sulfur material; the rest is EPA diesel fuel.

3.3 Spill-over Associated with New Winter Gasoline Formulations

[Ref. 1, Section 3.3.2] provides a discussion of the gasoline grades now carried by the SFPP pipeline system and the extent of "spill-over" and quality give-away.

For purposes of this discussion, we note that any of the Winter gasoline formulations simply would replace CBG Type 1 or Type 2 gasoline required in the Winter after 1999.

The costs associated with spill-over and quality give-away could increase, as the cost of producing Maricopa County gasoline increases, if the current pattern of spill-over persists. However, we found in our previous analysis that the cost of quality give-away is in the same range as the cost that would be incurred to eliminate most of the give-away. Thus, the cost of quality give-away associated with the new Winter gasoline formulations and the diesel fuel formulations is likely to be small or to be avoided altogether through investments in the distribution system to improve product handling capabilities.

3.4 Supply of Diesel Fuel in Arizona

This section discusses the supply of diesel fuel in Arizona, with particular emphasis on supply to mining areas, and the potential response of the refining sector and distribution system to adoption of a new diesel fuel formulation by Maricopa County.

3.4.1 Pattern of Diesel Fuel Supply

Diesel Fuel Supply to Arizona

Table 3.4 shows the sources and estimated volume of supply of diesel fuel to Arizona. We estimate that the volume of diesel fuel delivered to Arizona in 1997 was in excess of 46 K Bbl/day.

SFPP accounts for the bulk of diesel fuel delivered to Arizona. Small volumes of diesel fuel (used by the mining industry) are trucked in from El Paso and shipped via rail from the Gulf Coast. Low-sulfur diesel is supplied to northern Arizona out of New Mexico and Las Vegas.

Virtually all diesel fuel now supplied by California refineries to Arizona via the West pipeline is classified as EPA diesel.[4] The West pipeline carries no high-sulfur diesel fuel. Thus, no high-sulfur diesel reaches Yuma, Phoenix, or Tucson via the West pipeline or Las Vegas via the Cal-Nev pipeline.

All *pipeline* deliveries of high-sulfur diesel fuel to Arizona are via the East pipeline. Pipeline delivery data indicate that about 5.3 K Bbl/day are supplied via the East pipeline (this includes Road Forks). Only about a fifth of the high-sulfur diesel fuel carried by the East pipeline (1.1 K Bbl/day) are delivered to Phoenix. A small volume of high-sulfur diesel fuel apparently is trucked in to southeastern Arizona from El Paso.

Completion of the Longhorn pipeline to El Paso should increase the availability of both low- and high-sulfur diesel fuel to the Arizona market. (About one third of current diesel fuel production by Texas refineries is high-sulfur diesel.)

Diesel Fuel Supply to the Arizona Mining Industry

Table 3.5 shows our estimates of diesel fuel use in 1997 by the four largest mining companies in Arizona (Asarco Inc., BHP Copper Inc., Cyprus Climax Metals Co., and Phelps Dodge Corp.), broken out by type of diesel fuel and source of supply.

Except for the Bagdad mine operated by Cyprus (located northwest of Phoenix), the mines operated by the four companies are located south and east of Phoenix.

All diesel fuel purchased by mines for off-road use is untaxed (dyed) and virtually all purchases of diesel fuel by mines are for off-road use. Untaxed diesel fuel may be either EPA or high-sulfur diesel. Mining companies used about 6 K bbl/day of diesel fuel in 1997, about 60% of which was high-sulfur diesel.

Comparison of diesel purchases by the four mining companies with pipeline deliveries indicates that all of the high-sulfur diesel delivered to Phoenix (via the East pipeline) was used by the companies, but that less than half of the high-sulfur diesel delivered to the Road Forks and Tucson bulk terminals was used by the companies.

Expansion of mining operations and the development of a large, new mine by Phelps Dodge could increase the demand for untaxed diesel fuel in Arizona by over 2 K Bbl/day by the year 2000, or thereabouts.

4 A small volume of diesel delivered in Phoenix in 1997 was classified as CARB diesel. Some diesel shipped via the West pipeline and classified as EPA diesel, in fact, may be CARB diesel. However, refiners have a strong economic incentive to minimize such shipments. Discussions with West refiners indicate that they do not ship CARB diesel to Phoenix on a routine basis.

Table 3.4: Estimated Supply of Diesel Fuel to Arizona, by Source, 1997
(barrels/day)

Source	Bulk Terminal/ Area Supplied	Type of Diesel Fuel EPA	High-Sulfur	Total
West Pipeline		**31,400**	**-**	**31,400**
	Yuma (Imperial)	4,900	-	4,900
	Phoenix	24,200	-	24,200
	Tucson	2,300	-	2,300
East Pipeline		**7,500**	**5,300**	**12,800**
	Road Forks*	700	1,200	1,900
	Tucson	3,600	3,000	6,600
	Phoenix	3,200	1,100	4,300
El Paso	Southeast	**-**	**< 500**	**< 500**
Gulf Coast	East	**< 1000**	**-**	**< 1000**
New Mexico	North	?	**-**	?
Las Vegas	Northwest	?	**-**	?
Total				**> 46,000**

* Part of this volume may be distributed in New Mexico

Table 3.5: Arizona Mining Sector's Estimated Diesel Fuel Use, by Type and Supply Source, 1997*
(barrels/day)

Source of Supply	Type of Diesel Fuel** Low-sulfur	High-sulfur	Total
Phoenix	700	1,100	1,800
Tucson, Road Forks, & El Paso	500	2,600	3,100
Gulf Coast	<1,000	-	<1,000
Total	**2,200**	**3,700**	**5,900**

* Includes Asarco Inc., BHP Copper Inc., Cyprus Climax Metals Company, and Phelps Dodge Corp.
** Mines purchase only non-taxed (dyed) diesel fuel for off-road use.

Diesel Fuel Sales in Maricopa County

Only limited information is available on *sales* of diesel fuel statewide and in Maricopa County.[5] The Arizona Department of Transportation publishes information only on the statewide *use* of taxed diesel fuel. (This includes only on-road, taxed diesel, not off-road, untaxed diesel. Further, the state data reflect estimates of the volume of diesel fuel used, rather than purchased, in-state. For example, on-road diesel purchased in California, but used by a truck traversing Arizona, would be included in the estimate; on the other hand, diesel fuel purchased in Arizona but used out-of-state would be excluded.) Thus, although we developed estimates of diesel fuel *use* in Maricopa County, we do not have data on the volume diesel fuel *sales* in Maricopa County.

According to data collected by the Arizona Department of Transportation, sales of gasoline in Maricopa County in 1997 averaged just under 77 K Bbl/day. Pipeline deliveries of gasoline to Phoenix (combined West and East lines) averaged about 88.5 K Bbl/day. These data indicate that only about 13% of gasoline delivered to Phoenix via pipeline was sold outside of Maricopa County. Discussions with Phoenix Fuel and bulk terminal operators in Phoenix suggest that a larger share of diesel fuel is sold outside of Maricopa County, perhaps on the order of 40 to 45%. (Phoenix bulk terminals supply large volumes of diesel fuel to truck stops and mines located outside of Maricopa county.) Further, this share could increase if Maricopa County adopts new diesel fuel standards. (Trucking companies could adjust their fueling locations in response to price differentials between Maricopa County diesel fuel and EPA diesel fuel.)

Assuming today's level of demand for diesel fuel and that about 40% of diesel fuel delivered to Maricopa County is sold out-of-county, the demand for Maricopa County diesel fuel would be about 17 K Bbl/day. Deliveries of EPA diesel and (a small volume of) high-sulfur diesel would have to be about 11 K Bbl/day to satisfy demands in out-of-county areas now supplied from Phoenix.

3.4.2 Refining Sector Response

If new gasoline and/or diesel fuels standards are adopted for Maricopa County, refineries supplying Maricopa County could decide to produce the new gasoline of choice (in the Winter season), the new diesel of choice, or both. Capital investments required to produce the gasoline and the diesel fuel need not be coupled. Hence, for purposes of this analysis, one can concentrate on refiners' prospective responses to a new diesel fuel standard.

5 DOE reports diesel fuel sales by prime suppliers and by type of sale (sales to end users and sales for resale). Prime supplier diesel fuel sales generally correspond to the pipeline delivery data we already have used. DOE data on diesel fuel sales by type of sale significantly understate statewide sales.

Moreover, one can concentrate on the East refining center, because that is the source of most of the diesel fuel supplies to the mining areas. All high-sulfur diesel fuel supplied to the mining areas of Arizona comes from two refineries in the East refining center. Non-taxed EPA diesel supplied to the mining areas comes from the West, East, and Gulf Coast refining centers, in proportions that cannot be established readily.

Of the two East refineries that account for most of the diesel fuel supply to the mining areas, one produces only high-sulfur diesel; the other produces both high-sulfur and EPA diesel, but sells mainly high-sulfur diesel fuel in Arizona. The two supply little or no EPA diesel fuel to Maricopa County now. These refineries would be unlikely to invest to produce a new diesel fuel of choice for Maricopa County. Rather, they would continue to produce their current out-turn of high-sulfur and EPA diesel fuels. This outlook is based on discussions with East refiners and is consistent with principles of refining economics.

Two other refineries in the East refining center have the existing capability to supply high-sulfur diesel to Arizona – though they do not do so now – or to supply additional volumes of EPA diesel to Arizona. At least one of these refineries now sends EPA diesel fuel to the Phoenix area. One or both refineries might invest to supply the new diesel fuel of choice to Maricopa County. Such investments, if made, would not affect the volumes of non-taxed diesel fuel in the mining areas. Again, this outlook is based on discussions with East refiners. (However, given our estimates of diesel fuel sales in Maricopa County, West refiners could supply the entire demand for Maricopa County diesel fuel.)

In response to a new diesel fuel standard for Maricopa County, the refining sector as a whole (West, East, Gulf Coast, or other sources) will act to upgrade some volume of EPA diesel to the new diesel fuel of choice. That response likely will decrease correspondingly the overall supply of EPA diesel and induce a small increase the aggregate per-gallon cost of diesel fuel production. These effects could trigger (1) changes in the proportion of EPA diesel fuel in the non-taxed diesel fuel pool and (2) some increase in the cost of supplying the mining areas, depending on how the incremental refining costs are allocated across the various diesel fuel markets in Arizona.

3.4.3 Distribution System's Response

If a new diesel fuel standard is adopted for Maricopa County, the pipeline system and bulk terminals in Phoenix will have to handle an additional grade of diesel fuel.

SFPP's West line already handles both EPA diesel and CARB diesel up to the Imperial bulk terminal in California. According to information provided by SFPP, the West line between Imperial and Phoenix already is capable of handling CARB diesel. Adequate tankage also is available in Phoenix to handle CARB diesel. However, the West line is not now capable of handling a unique Maricopa County diesel fuel, i.e., a third diesel in addition to EPA diesel and CARB diesel.

The East line may have to add additional break-out tankage at Tucson in order to deliver an additional grade of diesel fuel (three grades of diesel in total) to Phoenix. (SFPP would need to conduct a study of the East line to definitively determine whether additional tankage would be necessary.) Apparently, the East line can now handle three grades of diesel, given that only two grades – Maricopa County diesel and either EPA diesel or high-sulfur diesel – were delivered to Phoenix. That is, the introduction of Maricopa County diesel in the East line would not impair deliveries of EPA and high-sulfur diesel to Road Forks and Tucson. However, without additional breakout tankage, the current system may be capable of handling only one other grade of diesel fuel (EPA or high-sulfur) between Tucson and Phoenix.

Seven bulk terminals in Phoenix handle diesel fuel. Only the SFPP bulk terminal handles high-sulfur diesel fuel. Other bulk terminals now handle only EPA diesel fuel (in addition to other refined products, such as gasoline and jet fuel).

The introduction of another grade of diesel fuel in Phoenix is unlikely to require bulk terminals to add tankage. There already is adequate aggregate tankage in Phoenix and, because most bulk teminals have multiple tanks for handling EPA diesel fuel, they generally have the flexibility to handle two grades of diesel. However, investments would be required to put in place separate loading systems for EPA and Maricopa County diesel.

4. REFINING ANALYSIS OF GASOLINE AND DIESEL FUEL FORMULATIONS

This section deals with the "refining analysis" portion of the study. It has three parts:

1. Analysis of the gasoline formulations
2. Analysis of the diesel fuel formulations
3. Comments on refineries <u>not</u> represented

We conducted the refining analysis to produce estimates, for each of the gasoline and diesel fuel formulations, of

- Incremental *refining costs* (including refinery operating costs, capital charges for required refinery investments, and ancillary costs);
- *Changes in fuel economy* (measured in miles/gal);
- *Investments* in new refining capacity for producing the various gasoline formulations; and
- *Physical properties* that bear on emissions performance

The first two sets of estimates are the primary determinants of the overall cost of the fuel formulations. The third set bears on the time of availability of the fuel formulations. The fourth set drives the analysis of the emission benefits of the fuel formulations (discussed in Section 5).

4.1 Refining Analysis: Gasoline Formulations

We conducted the refining analysis for the gasoline formulations using a refinery LP modeling system (**ARMS**, in this instance) to analyze a series of cases; each case representing prospective operations of a refining center (West and East, individually) producing one of the gasoline formulations (along with its other slate of products).

The methodology for this refining analysis was essentially the same as in our previous work on Summer gasoline formulations for Maricopa County. It is described in some detail in [Ref. 1: Section 4, Appendix A, and Appendix E].

For consistency, we used the same notional refinery profiles, techno-economic data, calibration, and key assumptions (e.g., no "quality shifting" with conventional gasolines produced for sale outside of Maricopa County) as in the previous work. We departed from the earlier methodology in only two ways.

- The analysis focused on the Winter season, rather than the Summer season, and on the current baseline gasoline and slate of proposed gasoline formulations.

- We represented two regional refining aggregates this time (West and East), rather than three as in the previous work. This time, we did not consider the Northwest aggregate,

Tables 4.1, **4.2**, and **4.3** (at the end of this section) show, respectively, the refining process capacity profiles for the West and East notional refineries represented in ARMS, the crude slates for the notional refineries, and product outputs for the notional refineries.

4.2 Refining Analysis: Diesel Fuel Formulations

Time did not permit us to analyze the diesel fuel formulations with our refinery LP model, as we did the gasoline formulations. Instead, we conducted a straight-forward technical analysis drawing on published information on diesel fuel economic and properties.

Table 4.2 summarizes the results of this analysis for each of the diesel fuel formulations.

4.2.1 Refining Costs

The incremental refining costs (defined above) for the diesel fuel formulations are average costs in excess of the average refining cost of EPA diesel fuel sold in Maricopa County (i.e., the baseline diesel fuel). In estimating refining costs for the diesel fuel formulations, the limited availability of published data on costs precluded our developing separate estimates of refinery operating costs, capital charges for required refinery investments, and ancillary costs, as we did for the gasoline formulations. Rather, we estimated a single cost value that embodies all three cost categories.

For simplicity and clarity, we show these cost estimates as point values (not as ranges). However, the cost estimates are subject to considerable uncertainty, because (1) they are not based on a rigorous methodology – that is, refinery LP modeling – and (2) the data sources on which we relied are incomplete and do not spell out their analytical methodologies. Consequently, we recommend that the estimated refining costs shown in Table 4.2 be viewed as having an uncertainty range of, say, ± 25%.

We estimated the refining costs of the various diesel fuel formulations as follows.

D1: Baseline EPA Diesel, Cetane Enhanced (+ 5 Cetane Numbers)

This formulation differs from the baseline diesel fuel only in the use of a cetane enhancer (usually an alky nitrate, such as ethyl hexyl nitrate) in an amount sufficient to raise the fuel's cetane number by 5 units. Use of cetane enhancers is common practice. Consistent with [Ref. 5], we estimate the cost of achieving a 5 unit improvement in cetane number to be about *1.5¢/gal.*

D2: Baseline EPA Diesel, Cetane Enhanced and 100 ppm Sulfur

This formulation differs from the baseline diesel fuel in two respects. Its cetane number is increased by 5 numbers through use of a cetane enhancer. Its sulfur content is reduced to 100 ppm – vs. 210 ppm for the baseline fuel – by hydrotreating one or more sulfur-bearing refinery streams (FCC feed or light cycle stock). For this analysis, we assumed that the cetane enhancement and the desulfurization have independent (i.e., not interactive) effects on the physical properties of this diesel fuel formulation.

We found no published estimates of the economics of hydrotreating diesel fuel precursors that are already low in sulfur. However, the results of the refinery LP runs for estimating the costs of the gasoline formulations (discussed in Section 4.1) contained some useful cost indicators. In particular, the marginal costs ("shadow prices") of diesel fuel output and diesel fuel sulfur specification in those modeling results suggest that the cost of desulfurization would be on the order of 2¢/gal.

Hence, we estimate the total refining cost of producing this diesel fuel formulation (for cetane enhancement and desulfurization) to be on the order of *3.5¢/gal*.

This estimate may be conservative in some situations, because it applies to a "stand-alone" project for diesel fuel upgrading. By "stand-alone", we mean a situation in which a refinery invests in new capacity and changes operations solely to upgrade its existing diesel fuel to the new formulation. If the refinery were to upgrade the quality of other products (say, part of its gasoline pool) at the same time, some of the capital charges for investments in new capacity would be allocated to the gasoline upgrading, reducing the indicated cost of the diesel fuel formulation.

D3: CARB diesel – Formula Properties with 200 ppm sulfur

Only small volumes of CARB diesel are produced to the property-based standard. Therefore, cost estimates for this diesel fuel formulation are unusually uncertain (but, on the other hand, of limited interest). We use CARB's own estimate of the cost of producing CARB diesel with the formula properties: about *10¢/gal* [Ref. 10].

CARB made this estimate more than four years ago, and it may be too high. But, producing CARB diesel to the property-based standard would be expensive – mainly because of the standard's low limit on aromatics content (< 10 vol.%). Indeed, all CARB diesel fuels produced with certified formulations (discussed below) have higher aromatics content (≈ 18 vol.% on average) than the property-based standard calls for.

D4: CARB Diesel – Average Properties Of Certified Alternative Formulations

For this diesel fuel formulation, we again used CARB's estimate of the refining cost: about *4¢/gal* (relative to EPA diesel fuel) [Ref. 10]. (The often-cited 6¢/gal figure was CARB's estimate relative to what is now off-road ("high sulfur") diesel fuel.)

D5: Advanced Blend (CARB diesel + Fischer-Tropsch)

We specified diesel fuel formulation to correspond to a 2:1 volumetric blend of CARB diesel and Fischer-Tropsch distillate (though it would not necessarily have to be produced that way).

As discussed above, we estimate that the CARB diesel constituent would have a refining cost of about 4¢/gal. We estimate that the Fischer-Tropsch distillate could be delivered to California for about 6¢/gal more than the production cost of CARB diesel (that is, about 10¢/gal more than the baseline diesel fuel).

This estimate is consistent with (1) delivered (CIF) prices of cargoes of Fischer-Tropsch distillates that (we understand) have been delivered to Los Angeles from the Royal Dutch/Shell Group's plant in Malaysia and (2) published estimates of the economics of Fischer-Tropsch synthesis with the latest technology and with remote (low cost) natural gas as feedstock [Ref. 7].

Taking the volume-weighted average of the incremental costs of the two constituents leads to an estimated cost of about *6¢/gal* for this diesel fuel formulation.

D6: Swedish Class 1 Diesel

Here again, we found no published estimates of the economics of producing this diesel fuel formulation. One can infer that it is very expensive to produce because (1) its property-based standard calls for exceptionally low levels of sulfur, aromatics, and poly-nuclear aromatics – each of which is costly to achieve – and (2) it has an unusually low distillation end-point (indicating that some volume of oil must be rejected from the distillate pool to the (lower-value) residual oil pool. Further, we understand that the Swedish government subsidizes its production by the equivalent of more than 35¢/gal.

Hence, for purposes of this study, we estimate its incremental cost to be about *32¢/gal*.

4.2.2 Physical Properties

We estimated the physical properties of the various diesel fuel formulations on the strength of existing diesel fuel specifications (as applicable) or published estimates, as follows.

D1: Baseline EPA Diesel, Cetane Enhanced (+ 5 Cetane Numbers)

All properties, except cetane number, are drawn from the 1997 AAMA diesel fuel survey for Phoenix [Ref. 3]. The cetane number is 5 numbers higher than the average value for Phoenix reported in [Ref. 3].

D2: Baseline EPA Diesel, Cetane Enhanced and ≤ 100 ppm Sulfur

Again, all properties are drawn from [Ref. 3], but with adjustments – based on engineering judgement – to aromatics content, poly-aromatics content, and density to reflect the secondary effects of the hydrotreating that reduces sulfur content to 100 ppm.

D3: CARB diesel – Formula Properties with ≤ 200 ppm Sulfur

We set the sulfur content of this diesel formulation at 200 ppm, to reflect the fact that the California refiners now produce EPA diesel fuel with an average sulfur content of 200 ppm. The California refiners would likely upgrade this EPA diesel to produce incremental CARB diesel for Maricopa County. Upgrading would be unlikely to increase the sulfur content of the diesel fuel.

We drew the aromatics content, poly-aromatics content, and cetane number directly from the general reference fuel specifications in the CARB diesel fuel regulation [Ref. 6]. The density and distillation estimates are intermediate values within the specified ranges in the general reference fuel specifications.

D4: CARB Diesel – Average Properties Of Certified Alternative Formulations

All properties are drawn from the 1996 API/NPRA survey [Ref. 4] and correspond to the volume-weighted average properties of the CARB diesel fuel actually produced in the California refineries in the 1996 Summer season. (Almost all CARB diesel is produced to the performance-based standard, through certified formulations; little is produced to the property-based standard.)

D5: Advanced Blend (CARB diesel + Fischer-Tropsch)

We specified the properties of this diesel fuel formulation to correspond to a 2:1 volumetric blend of CARB diesel and Fischer-Tropsch distillate. We computed volume-weighted average properties using the properties of CARB diesel discussed above [Ref. 4] and published properties of Fischer-Tropsch distillate [Ref. 7]. In this computation, we assumed that the properties of interest blended linearly.

D6: Swedish Class 1 Diesel

All of the properties except the distillation values correspond to the specification for Swedish Class 1 diesel fuel [Ref. 8]. We estimated the distillation values on the basis of the density specification, using engineering judgement.

4.2.3 Fuel Economy

We assume for this analysis that a diesel fuel's fuel economy (expressed in miles/gallon) is proportional to its energy density (expressed in M BTU/Bbl or in K BTU/gal). Physical considerations dictate that energy density decreases with decreasing aromatics content, decreasing density, and decreasing distillation temperatures (i.e., T_{10}, T_{50}, and T_{90}).

We estimated these properties for the baseline diesel fuel and for each diesel fuel formulation, as discussed in Section 4.2.2 above.

Then, we used a standard engineering correlation [Ref. 9, pg 200] to estimate energy density as a function of these physical properties. This step enables us to include the cost of the estimated gain or loss in fuel economy (miles/gal) in the total incremental cost of a diesel fuel formulation.

We used the following formula to estimate the cost *to Maricopa County* of a change in fuel economy associated with a given diesel fuel formulation.

$$\Delta \text{ Fuel economy cost (¢/gal)} = \Delta \text{ ED (\%)} * [\text{ARP (¢/gal)} + \text{IRC (¢/gal)}]$$

where

Δ ED is the change in energy density with respect to the baseline diesel fuel, expressed as a percentage of the energy density of the baseline diesel fuel;

ARP is the average retail price of diesel fuel in Maricopa County (including federal tax but *not* state tax) – close to 125¢/gal. at present; and

IRC is the incremental refining cost of the given diesel fuel formulation.

We used this same formula to estimate the change in fuel economy of the gasoline formulations, as described in [Ref. 1, pg. 51].

This formula is consistent with EPA's approach in assessing the costs of the federal RFG program.

4.3 Refineries Not Represented in the Refining Analysis

Any model-based analysis involves setting boundaries – that is, specifying which elements of the problem and which interactions are to be captured in the model and which are not. In the prior study, a key modeling issue was which refineries to include in the refining analysis and which to leave out.

As indicated in Section 4.1, this refining analysis considered two refining aggregates, made up of specified refineries in the Los Angeles and West Texas/New Mexico refining centers. [Ref . 1, Section 4.3.2], reprinted below, discusses refineries and refining centers not represented in the prior analysis. The discussion is still relevant and offers a useful perspective for this analysis.

[Ref. 1, Section 4.3.2]:

"Other refiners could enter the Maricopa County market in the future.

- Refineries located in the U.S. Gulf Coast region or in foreign countries from time to time ship gasoline to Los Angeles for sale in California, when market conditions in California are favorable for such imports. These refiners could supply gasoline to Maricopa County via Los Angeles harbor and the SFPP West pipeline.

  Alternatively, the Gulf Coast refiners could supply gasoline to Maricopa County via the proposed Longhorn Pipeline, should that pipeline (or a comparable one) be built.

- Giant Refining Co.'s refinery in Gallup, NM supplies portions of Arizona, and has in the past delivered gasoline to Maricopa County (by tank wagon).

- [Ultramar] Diamond Shamrock's refinery in McKee, TX could supply gasoline to Maricopa County via a newly-opened pipeline linking it to El Paso and the SFPP East pipeline.

  The [Ultramar] Diamond Shamrock refinery has a crude running capacity of 135 M Bbl/day and appears capable of producing at least 75 M Bbl/day of gasoline, including reformulated gasolines. Its product slate now includes federal RFG, for markets in Texas.

- MRC Refining, LLC has proposed to build a grass-roots refinery (the Maricopa refinery) south of Phoenix, which could supply Maricopa County directly, or through exchange or trade contracts.

  The Maricopa refinery would have a crude running capacity of 75 K Bbl/day. Its crude slate would comprise California crude oils (available via the All American Pipeline, whose right-of-way is adjacent to the refinery site). The refinery would produce about 40 K Bbl/day of gasoline. Its design process configuration would enable it to produce conventional or reformulated gasolines. Because it is not yet under construction, its process configuration could be tailored to produce gasoline for Maricopa County in compliance with the new gasoline standard that is adopted.

We chose not to represent any of these in the refining analysis.

We did not include the Giant Refining Co. refinery because it does not now supply gasoline to Maricopa County, and it would be a small supplier in the Maricopa County market if it were to re-enter it.

We did not include the [Ultramar] Diamond Shamrock refinery because (1) it has not yet filed any AGQM reports, indicating that it has not yet produced any gasoline that could be sold in Maricopa County, (2) we have no information regarding the timing and extent of its prospective participation in the Maricopa County market, (3) adding it to our East refining aggregate would not produce a significant change in the estimated average incremental costs of the proposed gasloine standards, and (4) adding it to our East refining aggregate might mask the economic impacts on the West Texas/New Mexico refiners of the proposed gasoline standards.

The Maricopa refinery is not yet in existence. We did not include it because we chose not to make assumptions regarding its status or prospective start-up date.

Finally, we did not include remote refineries, such as those in the U.S. Gulf Coast refining center. U.S. Gulf Coast refiners in particular could supply Maricopa County on a sustained basis in the future, depending on the gasoline standards established for Maricopa County, circumstances in the broader gasoline market, and the existence of pipeline capacity between the Gulf Coast and El Paso (e.g., the proposed Longhorn pipeline). However, including the Gulf Coast refineries in this analysis would expand its scope unduly and would involve speculating on a number of economic and business factors outside of Arizona's control.

The entry of any or all of these refineries into the Maricopa County market would likely increase competition in the market. However, such entry(s) would be unlikely to change the overall pattern of incremental refining costs (at the refinery gate) and cost-benefit relationships among the proposed gasoline standards considered in this analysis. Establishing those incremental costs and relationships was the objective of the refining analysis."

[We understand that Ultramar Diamond Shamrock's McKee refinery is now supplying gasoline to Maricopa County through the East pipeline system. This development does not, in our view, significantly change the refining economics of the West Texas/New Mexico refining center – for purposes of estimating the cost of proposed gasoline formulations for Maricopa County.]

Table 4.1: Refining Process Capacity for Refinery Aggregates and Notional Refineries
(barrels per calendar day)

Refining Processes	Refinery Aggregates East	Refinery Aggregates West	Notional Refineries East	Notional Refineries West
Number of Refineries	3	7	-	-
Complexity	8.0	12.1	8.0	12.1
Distillation:				
Crude Distillation	175,300	1,109,285	60,000	150,000
Vacuum Distillation	51,000	645,610	-	-
Conversion Processes:				
Fluid Cat Cracking	56,100	404,270	19,200	54,700
Hydrocracking	0	208,370	0	28,200
Coking: Delayed	2,400	319,130	800	48,800
Coking: Fluid	0	42,000	0	0
Upgrading Processes:				
Alkylation	20,800	93,800	7,100	12,700
Cat Polymerization	0	2,800	0	400
Pen/Hex Isomerization	0	19,000	0	2,600
Reforming: Low Pressure	38,000	84,200	13,000	11,400
High Pressure	9,500	192,620	3,300	26,000
Oxygenate Production:				
MTBE Plant	0	6,200	0	800
Desulfurization:				
Distillate	42,800	196,880	14,600	26,600
FCC Feed	0	419,960	0	56,800
Naphtha & Isom Feed	0	5,700	0	800
Reformer Feed	53,500	241,160	18,300	32,600
Resid	0	15,300	0	2,100
Other Processes:				
Solvent Deasphalting	0	0	0	0
Isomerization: C4	4,500	8,300	1,500	1,100
Hydrogen Plant (MM cf/d)*	0	572	0	77

* Conversion to FOEB -- 21,000 SCF/FOEB.

Table 4.2: Crude Oil and Other Inputs for the Notional Refineries*
(thousand barrels per day)

Inputs/ Outputs	API Gravity	Specific Gravity	% Sulfur	Notional Refineries East	West
Crude Oil Inputs:					
Composite: Light, LoSulfur	36.3	0.843	0.38%	45	
Composite: Medium, MedSulfur	33.2	0.859	1.47%	13	
Composite: West Domestic	20.0	0.934	1.24%		66
Composite: West Imports	29.7	0.878	1.23%		13
Alaskan North Slope	27.5	0.890	1.11%		71
Total:				**58**	**150**
Average Crude Oil Quality:					
API Gravity				0.0	0.0
Specific Gravity				0.000	0.000
Sulfur Content (%)				0.00%	0.00%
Other Inputs:					
Alkylate					2
Isobutane				1.4	1
Gas Oils					3
MTBE					6.3
Methanol					0.3
Naphtha					1
Natural Gas Liquids					1.3

* Summer 1996 baseline.

Table 4.3: Product Outputs for the Notional Refineries*
(thousand barrels per day)

Inputs/ Outputs	Notional Refineries	
	East	West
LPGs	1.6	5.0
Alkylate	-	-
Gasoline:	**28.0**	**90.0**
Conventional	20.0	9.0
Maricopa Co.	8.0	9.0
California RFG	-	72.0
Jet Kerosene	4.0	22.0
Distillate:	**17.0**	**31.0**
Low Sulfur	12.0	23.0
High Sulfur	5.0	8.0
Gas Oil	-	-
Residual Oil:	**4.0**	**1.0**
< 0.7% Sulfur	1.0	-
> 3.0 % Sulfur	3.0	1.0
Asphalt	3.0	2.0
Coke	0.2	9.7
Total:	**57.8**	**160.7**

* Summer 1996 baseline.

5. ANALYSIS OF EMISSION REDUCTIONS ASSOCIATED WITH THE GASOLINE AND DIESEL FUEL FORMULATIONS

Task 4 (Emissions Analysis) of the SoW requires the "…assess[ment of] the emissions impacts of each [fuel formulation] option identified in Task 1 using existing models and analytical methods, to the extent available …" This section presents the tools and methodologies employed to conduct the required emissions analysis. Topics addressed include:

1. A brief discussion of the emissions of interest,
2. The sources of these emissions affected by changes in fuel formulation,
3. The emissions models used to estimate fuel-driven emissions impacts, and
4. The baseline emission levels against which fuel driven-impacts were evaluated.

5.1 Emissions of Interest

The emissions of interest in this analysis span a broad range of pollutants in recognition of the broad scope of current air quality planning efforts in Maricopa County. Planning efforts are currently underway to address ozone, carbon monoxide, and particulate air pollution in the County and, as a result, emissions influencing each of these pollutants are of interest. Such emissions include:

- **Volatile Organic Compounds (VOC)**, which are precursors of ozone,
- **Oxides of Nitrogen (NO_x)**, which participate in both the ozone and particulate production process,
- **Carbon Monoxide (CO)**, and
- **Particulate Matter (PM)**.

PM emissions are of interest in two forms. **PM-10**, that portion of total particulate that has a mean aerodynamic diameter of 10 microns or less, is of direct interest since it is the primary focus of the current Maricopa County PM planning process. Additionally, **PM-2.5**, that portion of total particulate that has a mean aerodynamic diameter of 2.5 microns or less, is of interest because: (1) it is a good surrogate for assessing the impacts of PM control on the local "brown cloud" phenomenon and (2) recently adopted revisions to the national ambient air quality standard (NAAQS) for PM have been established in the form of PM-2.5 limits.

The SoW also requires an assessment of **hazardous air pollutant (HAP)** impacts as a secondary requirement of the emissions analysis. In fulfillment of this requirement, each gasoline formulation option was analyzed to estimate impacts on benzene, 1,3-butadiene, formaldehyde, and acetaldehyde emissions. These four compounds are generally recognized as the primary HAP's associated with gasoline combustion and, therefore, should provide an accurate assessment of the overall hazardous air pollutant impacts associated with each formulation. For diesel fuel formulations, no explicit analysis of hazardous air pollutant impacts was performed since there is ongoing debate over the health implications of diesel particulate. This debate centers on whether or not carbonaceous diesel particulate is itself a hazardous air pollutant. Given the fact that such PM is a primary exhaust component associated with diesel fuel combustion, the result of such debate will greatly influence the overall impacts of diesel fuel control on HAP's. In the interim, an assessment of the *potential* HAP impacts of diesel reformulation can be derived through the estimated fuel option impacts on carbonaceous PM emissions. Throughout this report, the terms *hazardous air pollutant* and *toxic* emissions are used interchangeably.

This report addresses two types of fuel reformulation, wintertime gasoline reformulation and year-round diesel fuel reformulation. The seasonal aspect of the evaluated gasoline formulation options affects the emissions of *primary* interest. By far, the primary pollutant of interest for assessing the effectiveness of wintertime gasoline reformulation is CO. Exceedances of the NAAQS for CO are a wintertime phenomena and gasoline combustion accounts for the bulk of CO emissions. Conversely, ozone exceedances are a summertime phenomena and, therefore, will be unaffected by wintertime gasoline formulation. PM impacts are of interest for both gasoline and diesel fuel options, but it must be recognized that while diesel formulations will affect PM on a year-round basis, the gasoline formulations evaluated will carry only a seasonal (i.e., wintertime) impact. PM exceedances are a year-round phenomena, but only those exceedances observed during the wintertime months can be affected by wintertime gasoline reformulation. For this reason, the wintertime gasoline cost effectiveness estimates presented in Section 6 of this report reflect the cost of gasoline reformulation per metric ton of CO removed. Emission impact estimates for other pollutants are presented, but are not included in the cost effectiveness calculations.

Gasoline and diesel fuel reformulation affects two specific sources of emissions in Maricopa County. These sources consist of: (1) on-road gasoline and diesel powered passenger cars and trucks and (2) off-road gasoline and diesel powered vehicles and engines. The emissions impacts of specific fuel formulations can vary with vehicle or engine technology (e.g., catalyst-equipped vehicles versus non-catalyst vehicles) and it is, therefore, important to consider specific technology penetrations in deriving aggregate fuel-related impacts. Section 5.2 describes the various methodologies used to ensure a *reasonable* accounting of the various vehicle and engine technologies in use.

5.2 Emissions Modeling Tools

The SoW requires that the emissions impact analysis be performed using "existing models and analytical methods, to the extent available." Unfortunately, their are no widely accepted, peer-reviewed modeling tools available to definitively estimate the emissions impacts of either wintertime gasoline or diesel fuel reformulation. Nevertheless, there are several existing models which can be used to support the required emissions analysis. These models include:

- The EPA **MOBILE5a** emission factor model (VOC, CO, and NO_x),
- The EPA **PART5** emission factor model (PM-10, PM-2.5, SO_2),
- The CARB **EMFAC7G** emission factor model (VOC, CO, NO_x, PM),
- The EPA reformulated gasoline **Complex Model** (VOC, NO_x, HAP's),
- The CARB reformulated gasoline **Predictive Model** (VOC, NO_x, HAP's), and
- The EPA reformulated gasoline **CO [Complex] Model** (CO).

The first three of these models (MOBILE5a, PART5, and EMFAC7G) are "fleetwide emission factor models" designed to assist air quality planners in the development of regional emission inventories. Each incorporates a limited ability to evaluate gasoline fuel quality impacts on emissions, but these abilities are too limited to differentiate the between the emissions producing properties of the fuels included in this study. Moreover, none include any type of diesel fuel formulation algorithms. The strengths of all three models is reflected in the degree of *vehicle* technology considerations inherent in emission factor predictions, but all are lacking in the ability to model fuel-related emissions impacts.

Dynamic MOBILE5a fuel responses are limited to changes in gasoline vapor pressure and oxygen content (additionally, static responses are included for federal reformulated gasoline via an on/off switch, but the activated modeling algorithms are not sensitive to user-input fuel properties). Neither vapor pressure or oxygen content are properties of primary importance in the Maricopa County wintertime gasoline evaluation. County baseline fuel already reflects low vapor pressure and oxygenate usage at the maximum legal blending limit. Those properties of Maricopa County gasoline which can be targeted for further regulation (e.g., sulfur content, aromatics content) cannot be evaluated using the MOBILE5a model. The MOBILE5a model includes no diesel fuel formulation algorithms.

Similar limitations apply to the CARB's EMFAC7G emission factor model. These limitations, in conjunction with the fact that the EMFAC7G model is designed to reflect the emissions performance of California-certified passenger cars and trucks, renders EMFAC7G an inappropriate model for assessing impacts on the primarily federally-certified fleet of vehicles in operation in Maricopa County.

MOBILE5a does include a robust treatment of evaporative VOC emissions for gasoline-powered passenger cars and trucks, using fuel RVP as an indicator of evaporative emissions potential. In fact, the evaporative emissions algorithms encoded in the EPA's reformulated gasoline Complex Model are taken directly from MOBILE5a. As such, MOBILE5a represents the current state-of-the-science tool for estimating fuel-related evaporative emissions impacts. However, evaporative VOC emissions are not a key element of the wintertime gasoline analysis for three reasons: (1) wintertime evaporative emissions are much less significant than corresponding summertime emissions due to reduced ambient temperatures, (2) VOC emissions are not a primary focus of the wintertime gasoline analysis, and (3) all wintertime gasoline options evaluated in this study reflect identical RVP quality.

The PART5 model is the EPA's particulate emissions counterpart to MOBILE5a. Like MOBILE5a, PART5 is not specifically designed to evaluate detailed differences in fuel composition. However, PART5 does include basic fuel formulation response algorithms to estimate the PM emissions impact of the federal reformulated gasoline program. These algorithms are fairly basic, depending entirely on only two specific fuel-related parameters. Fuel-driven impacts on carbonaceous PM are assumed to be proportional to fuel-related VOC impacts. Fuel-driven impacts on sulfate PM are assumed to be proportional to fuel sulfur content. While the accuracy of these PART5 impact assumptions (especially that related to the proportionality between carbonaceous PM and VOC) has not been confirmed through detailed test program results, the theory behind the adjustments is fundamentally sound. Moreover, these reflect the only PM-related gasoline impact algorithms currently available for application.

PART5 does have additional limitations relative to a detailed assessment of particulate impacts. While estimates of primary carbonaceous PM and both primary and secondary sulfate PM are produced, no estimates are generated for either secondary nitrate or secondary organic PM. Therefore, alternative techniques are required to supplement PART5 estimates. For secondary nitrate PM, the most reliable methodology appears to be the simple application of a secondary nitrate PM conversion factor to available Maricopa County NO_x inventories. While this approach can only be viewed as a gross estimate of secondary PM formation, it is equivalent to the approach employed in PART5 for sulfate PM and, therefore, should provide for equally accurate impact estimates. Secondary organic PM tends to be substantially less significant (on a mass basis) than either secondary sulfate or nitrate PM. Failure to account quantitatively for secondary organic PM impacts should not alter study results to any significant degree and, therefore, such impacts are treated only qualitatively in this analysis.

The EPA Complex Model (including the supplemental CO component) and the CARB Predictive Model were developed specifically to evaluate fuel quality impacts on emissions. However, the weaknesses of these models are complementary to those of the fleetwide emission factor models described above (i.e., MOBILE5a, PART5, EMFAC7G). Whereas the emission factor models incorporate comprehensive treatment of vehicle technologies and allow detailed fleetwide impacts to be assessed, the Complex and Predictive Models consider only limited vehicle technology impacts. The Complex Model estimates impacts specifically for a 1990 fleet of vehicles and is not sensitive to changes in fleetwide technology characteristics. The Predictive Model is somewhat more sensitive to vehicle technology in that it includes components explicit to 1981 through mid-1990's technology, but it still lacks specific treatments for pre-1981 and Tier I and newer technologies. Moreover, the Predictive Model has no CO component, limiting its utility to VOC, NO_x, and HAP's evaluation.

Given their ability to evaluate detailed gasoline property impacts on emissions, the Complex and Predictive Models are clearly the models of choice for evaluating gasoline property changes within the context of their inherent limitations. (Neither model includes a diesel fuel component.) These same limitations were identified and discussed in detail during the summertime gasoline analysis performed in support of the VEOP. As documented in the report summarizing that work (*Assessment of Fuel Formulation Options for Maricopa County*, MathPro, Inc., November 7, 1996), both Complex and Predictive Model impact estimates were adjusted for changes in fleet technology by factoring out the effects of fuel sulfur on oxidation catalyst vehicle NO_x and pre-catalyst vehicle (and engine) VOC, CO, and NO_x. The theory behind these adjustments is that (non-SO_2 and non-PM) fuel sulfur impacts are likely to be restricted to catalyst efficiency impacts. Therefore, emissions from vehicles without catalysts will be unaffected by changes in fuel sulfur. While no additional adjustments were made for other fuel parameters, emissions sensitivity to fuel sulfur is among the most significant fuel formulation impacts.

Some concern has been expressed regarding the use of the Complex and Predictive Models for wintertime fuel impact analysis since these models were developed on the basis of Federal Test Procedure (FTP) testing which occurs at temperatures between 68°F and 86°F. While this is an important issue in general, it is of lesser importance in Maricopa County. Wintertime temperatures in Maricopa County average between 55°F and 65°F, not unreasonably different than the lower-end temperatures of the FTP. For this reason, as well as the fact that there is no alternative analysis tool available for modeling wintertime impacts, these models represent the best available impact estimation tools for this study.

5.2.1 Gasoline Formulation Modeling Approach

Tables 5.1A and 5.1B present the modeling approaches used for all gasoline fuel formulation analysis. Wherever possible, these approaches rely on one or more of the existing modeling tools described above. Since specific adjustments were required to estimate the emissions impacts of fuel formulation changes for the various vehicle (and engine) catalyst technologies found in the Maricopa County fleet, all gasoline impact analysis was performed at a catalyst technology level-of-detail and aggregated on the basis of vehicle miles of travel (VMT)-weighted technology market penetrations to derive overall gasoline formulation impact estimates. In other words, impact estimates were developed separately for non-catalyst, oxidation catalyst, and three-way catalyst technologies and these individual impacts were aggregated in accordance with evaluation year-specific technology fractions. Technology fractions for each evaluation year consider penetrations within the passenger car, light truck, heavy truck, and motorcycle sectors. The only exception to this approach was for PM, where the PART5 model was used to estimate fleetwide technology-weighted emissions impacts directly using encoded technology fraction algorithms applicable to the specific evaluation year. All gasoline powered off-road vehicle and engine impacts were assumed to be equivalent to non-catalyst on-road vehicle impacts.

The EPA Complex Model was used to estimate gasoline-related CO, VOC, and NO_x impacts. As described above, the effect of changes in gasoline sulfur content was factored out of emissions impact estimates for non-catalyst vehicles (as well as NO_x impact estimates for oxidation catalyst

Table 5.1A: Modeling Approach for Wintertime Gasoline Analysis		
Pollutant	**Target Inventory Source**	**Modeling Tool(s)**
CO	Pre-Catalyst On-Road Vehicles and All Off-Road Vehicles	**EPA Complex Model for CO** (adjusted to eliminate effects of fuel sulfur changes)
	All Other On-Road Vehicles	**EPA Complex Model for CO** (without adjustment)
Exhaust VOC	Pre-Catalyst On-Road Vehicles and All Off-Road Vehicles	**EPA Complex Model** (adjusted to eliminate effects of fuel sulfur changes)
	All Other On-Road Vehicles	**EPA Complex Model** (without adjustment)
	Pre-Catalyst On-Road Vehicles and All Off-Road Vehicles	**EPA Complex Model** (adjusted to eliminate effects of fuel sulfur changes)

Table 5.1A: Modeling Approach for Wintertime Gasoline Analysis		
Pollutant	**Target Inventory Source**	**Modeling Tool(s)**
NO_x	Oxidation Catalyst On-Road Vehicles	**EPA Complex Model** (adjusted to eliminate effects of fuel sulfur changes)
	All Other On-Road Vehicles	**EPA Complex Model** (without adjustment)

Table 5.1B: Modeling Approach for Wintertime Gasoline Analysis		
Pollutant	**Target Inventory Source**	**Modeling Tool(s)**
Evaporative VOC	All On- and Off-Road Vehicles	**MOBILE5a**
PM-10 and PM-2.5	All On- and Off-Road Vehicles	**PART5** (augmented with external secondary nitrate estimates)
HAP's	All On- and Off-Road Vehicles	**EPA Complex Model** (estimated as fraction of VOC emissions)

vehicles). The CARB Predictive Model was not used for this study of wintertime gasoline formulations since CO emissions are of primary interest and the Predictive Model does not include a CO component.

The EPA MOBILE5a model was used to estimate gasoline-related evaporative VOC impacts. While each of the alternative wintertime gasoline options evaluated in this study is considered to have identical evaporative emissions potential, a baseline fuel evaporative VOC adjustment was required to avoid overestimating gasoline option evaporative benzene (a hazardous air pollutant) impacts. This adjustment is described in Section 5.4 below.

The EPA PART5 model was used to estimate carbonaceous and sulfate PM impacts. No modification was made to the PART5 assumption that 12 percent of emitted SO_2 is subsequently converted to sulfate PM. Given the unavailability of a Maricopa County-specific estimate for this secondary sulfate conversion rate, the EPA default conversion fraction was retained. Secondary nitrate PM impacts were derived through estimated changes in the Maricopa County NO_x inventory in conjunction with an assumed secondary nitrate conversion fraction of 2 percent. The 2 percent factor was derived from a secondary particulate report prepared by EEA for the EPA [Ref. 12]. Material reviewed for this same report implies that the actual secondary sulfate conversion rate may be much higher than the 12 percent assumed in PART5 and to the extent that this is true, the gasoline-related PM impacts estimated in this study are conservative. Secondary organic PM impacts were estimated only in a qualitative sense on the basis of fuel olefin and aromatic content, the estimates for which appear in Appendix D.

Hazardous air pollutant impacts were derived using the EPA Complex model in conjunction with Maricopa County VOC inventories. The Complex Model produces emission factor estimates for both total VOC and component HAP's and the ratio of these estimates can be used to evaluate relative gasoline formulation HAP's impacts.

5.2.2 Diesel Formulation Modeling Approach

Analysis of the effects of gasoline reformulation on emissions is aided by the fact that both the EPA and the CARB have developed analytical tools to estimate such effects (as described above). In contrast, there is no such tool available for analysis of the effect of diesel fuel composition on emissions. However, there has been some interest in this topic for the last decade, and there are a range of data sources that have estimated diesel fuel effects on emissions through the testing of one or more light- or heavy-duty diesel engines. A recent review of applicable literature conducted by Sierra Research for WSPA (*Analysis of Diesel Fuel Quality Issues in Maricopa County, Arizona*, Sierra Research, Inc., December 29, 1997) found that most of the available and well documented data on the fuel effects on emissions pertained to 1991 and newer model year heavy-duty engines, while data on pre-1991 heavy-duty and all light-duty engines was relatively limited or incomplete.

Maricopa County emission inventories indicate that light-duty diesel vehicles (cars and light trucks) accumulate less than 5 percent of total estimated diesel vehicle VMT. The light-duty diesel contribution to emissions is even smaller since their mass emission rate per mile of travel is much less than the corresponding emission rate of heavy-duty diesel vehicles. In fact, the net emissions contribution of light-duty vehicles is less than 2 percent of total diesel vehicle emissions for all pollutants. Therefore, a focus on heavy-duty diesel vehicle (HDDV) impacts alone will nevertheless result in reasonably accurate emissions impact estimates for the entire diesel fleet. Given the lack of available fuel impact data for light-duty diesel engines, such a HDDV-focused approach was used for this analysis.

HDDV's can be subdivided into three sub-classes termed light heavy (LHDDV), medium-heavy (MHDDV), and heavy-heavy (HHDDV). Of these classes, light-heavy diesels are a relatively recent phenomenon and cover vehicles in the 8,500 pound to 16,000 pound gross vehicle weight rating (GVWR) category (i.e., industry vehicle classes II(b), III, and IV). **Table 5.2** shows the national sales of HDDV engines by sub-class, and the very rapid growth of light-heavy duty diesels in the post-1990 time frame is obvious.

Table 5.2. U.S. Diesel Sales by Heavy-Duty Engine Sub-Class (including bus engines)

Year	Light-Heavy	Medium-Heavy	Heavy-Heavy
1980	0	55,850	97,502
1985	105,900	86,210	129,020
1990	92,800	76,910	121,375
1995	244,500	114,230	210,965

Source: AAMA Factory Sales Reports.

The Sierra report has indicated that the effects of fuel composition on engine emissions is sensitive to the details of the technology employed in the engine. The broadest technology differences between engines are in combustion chamber type (denoted as direct injection versus indirect-injection) the presence of a turbocharger, and potentially the operating cycle (denoted as two-stroke versus four-stroke). However, by 1990, almost all diesel engines were of the turbocharged, direct injection, four-stroke type, so that other technologies were limited primarily to pre-1990 engines.

Even among the pre-1990 engines, only some light-heavy diesel engines were of the indirect injection type and were not turbocharged. Virtually all medium-heavy and heavy-heavy engines are turbocharged, and all of these engines are of the direct-injection type. Two-stroke diesel engines were produced only by Detroit Diesel (DDC) and have relatively limited market share in the pre-1990 time frame. Hence, analysis for the 2000 to 2010 time frame can assume a technologically homogenous population of heavy-duty diesel engines with little error. Engine model-to-model differences in fuel response do, however, exist.

Emissions standards for diesel engines have also been decreasing over time, as shown in **Table 5.3**. Although the standards changed several times over the 1976-1990 period, the basic design of most engines did not change and the more stringent emission standards were met by modest evolutionary improvements to engines. 1991 and newer standards required very significant technological upgrades with ultra-high pressure fuel injection, "quiescent" combustion chambers, and electronic injection timing control. Hence, it is possible that the response of post-1990 and pre-1991 engines to fuel composition changes are not similar.

A review of available literature found 15 recent technical papers discussing the results of engines tested on a range of fuels of widely varying composition. With one exception, the papers reported detailed fuel properties (except for polycyclic aromatics as distinct from mono-aromatics) and emissions of HC, CO, NO_x and PM. The one exception was a paper that reported only PM emissions. Several papers reported fuel polycyclic aromatic content, while another subset provided data on the soluble organic fraction (SOF) of particulate, that is considered by some as an indicator of the toxicity of emitted PM. A list of the papers is included in **Table 5.4**, and the majority of engines tested were of 1991 and newer vintage. Another drawback of the available data is that 10 of 18 engines tested are the DDC Series 60 Model and the database cannot be considered as having a mix of engines representative of the fleet.

All reported data was assembled; the resulting database containing emissions data on 160 engine/fuel combinations for HC, CO and NO_x emissions and 169 engine/fuel combinations for PM. All data were collected over the U.S. Federal Transient Test Procedure, although several papers reported hot start data only. The absence of the composite emission results (weighted hot/cold start) is not considered a significant problem since fuel related trends are unlikely to be affected significantly during cold start relative to a hot start test.

Table 5.3: Federal Exhaust Emission Standards for Heavy-Duty Diesel Engines (grams per brake-horsepower hour)

Model Year[1]	HC	CO	NO_x	$HC+NO_x$	PM	Opacity	
1970-73	--	--	--	--	--	Accel Lug	40% 20%
1974-78	--	40	--	16	--	Accel Lug Peak	20% 15% 50%
1979-83	1.5	25 25	-- --	10 5	-- --	Accel Lug Peak	20% 15% 50%
1984[2]	1.3 0.5	15.5 15.5	10.7 9.0	-- --	-- --	Accel Lug Peak	20% 15% 50%
1985-87	1.3	15.5	10.7	--	--	Accel Lug Peak	20% 15% 50%
1988-90	1.3	15.5	6.0	--	0.60	Accel Lug Peak	20% 15% 50%
1991-93	1.3	15.5	5.0	--	0.25	Accel Lug Peak	20% 15% 50%
1994-97	1.3	15.5	5.0	--	0.10	Accel Lug Peak	20% 15% 50%
1998+	1.3	15.5	4.0	--	0.10	Accel Lug Peak	20% 15% 50%

1. The steady-state procedure was used through 1984 and the transient procedure has been used since 1985.

2. Manufacturers had the option of using the 1983 procedure and standards, or standards of 1.3 HC, 15.5 CO and 10.7 NO_x on the transient procedure, or standards of 0.5 HC, 15.5 CO and 9.0 NO_x on the steady-state procedure.

Source: EPA

A detailed regression analysis of the available data was utilized to develop a model which relates fuel properties to engine emissions. Various models were attempted and the best model type appeared to be of the log-log type, where the logarithm of the dependent variable (i.e. emissions) is a function of the logarithms of the independent variables (i.e. fuel properties). This type of model is appealing as it implies a relationship between the percent charge in emissions and the percent change in fuel properties, rather than an absolute relationship. Fuel variables were selected so that they were not linearly interrelated and included sulfur and aromatic content, cetane number and relative density (i.e., actual fuel density normalized for density changes with aromatic content).

The model for each pollutant proved highly successful in that the regressions had high coefficients of correlation (r^2), excellent F statistics and highly significant coefficients (i.e., t statistics >> 2). The models were developed by first regressing the emissions against all fuel variables available, and then selecting those variables with statistically significant coefficients.

Although the models were statistically significant, one unexpected result was obtained: HC emissions increased with decreasing aromatic content, which is in opposition to the results of many studies. A more detailed analysis found that both HC emissions and PM emissions were sensitive to the mono-aromatic and polycyclic aromatic content; regressions with both variables illustrated the differential sensitivity to these two types of compounds, but these regressions were performed on a smaller database of 84 records that had information on polycyclic aromatic content. Due to the reduced size of the database and the correlation between aromatic and polycyclic aromatic content, the model for HC emissions did not result in statistically significant coefficients for the aromatic and polycyclic aromatic content variables. However, the models with these variables were more appealing from an engineering analysis viewpoint, and both the best statistical model and the model with polycyclic aromatic content as an independent variable were retained.

Table 5.4: Summary of Engine/Fuel Combinations Tested

SAE Paper	Engine(s)	Model Year	Fuels Tested	Emissions Tested
892072	Cummins NTCC400	1987	8	All + SOF
	DDC Series 60	1988 (modified)	8	All + SOF
	Navistar 7.3 L	1981	9	All + SOF
902171	DDC Series 60	1991 (prototype)	8	All
902172	Navistar DTA466	1991 (prototype)	11	All + SOF
902173	DDC Series 60	1991+	18	All (Hot Start)
912425	DDC Series 60	1991+	8	PM + SOF
922267	Navistar DT466	1993	12	All + SOF (Hot Start Only)
932731	DDC Series 60	1991 (prototype)	2	All (Hot Start Only)
932734	DDC Series 60	1991 (prototype)	12	All + SOF (Hot Start Only)
932767	DDC Series 60	1991 (prototype)	3	All + SOF
932800	Cummins N14	1994	8	All + SOF (Hot Start Only)
941020	DDC Series 60	1994 (prototype)	10	All
	DDC Series 60	1998 (prototype)	9	All
950250	Navistar DTA466	1994 (prototype)	11	All
950251	DDC Series CO	1998 (prototype)	11	All
961973	Cummins L10	1990	2	All
970758	DDC Series 60	1994	8	All + SOF
	Cummins B5.9	1994	8	All + SOF

The models are shown in **Table 5.5**. The intercept term is not shown, since a dummy variable was utilized for each engine tested to normalize emissions from different engines with the same fuel.

These regressions were utilized to model the effect of different fuel composition changes on emissions. As noted, six different diesel formulations were selected for analysis, as noted below.

- D1: Baseline EPA diesel, cetane enhanced
- D2: Baseline EPA diesel, cetane enhanced and 100 ppm sulfur
- D3: CARB Diesel – formula properties with 200 ppm sulfur
- D4: CARB Diesel – average properties of certified alternative formulations
- D5: Advanced Blend (CARB diesel and Fischer-Tropsch distillate)
- D6: Swedish Class 1 diesel

The resultant predictions of changes to exhaust emissions for the six options are shown, relative to the current EPA baseline fuel, in **Table 5.6**.

While these estimates are for exhaust (primary) particulate, the fuels can also affect secondary particulate for sulfate and nitrate based particulate. It should be noted that sulfate is also present in primary particulate, and is estimated to account for 2 to 4 percent of primary particulate at fuel sulfur levels of 210 ppm. For the analysis, we have also estimated that secondary particulate is affected by fuel composition changes, assuming:

- Sulfate-based secondary particulate are changed in proportion to fuel sulfur levels.
- Nitrate-based secondary particulate are changed in proportion to emissions changes in NO_x.

A further assumption is that the model is applicable to pre-1990 engines and off-road diesel engines emissions. There is limited data on pre-1990 engines in the database, and the sensitivity of these engines to fuel composition changes appear to be statistically similar to other 1991 and newer engines in the database, with the models matching the data closely. Based on this limited confirmation of model accuracy, EEA believes that the model is likely applicable to most diesel engines in the field, at least for a preliminary estimate of fuel composition effects.

5.3 Baseline Emission Inventories

Since each of the fuel formulation analysis models used in this study express emissions impacts in terms of percentage change, baseline emission inventories are required to convert fuel model predictions into mass emissions impacts. These baseline inventories should reflect the emissions levels expected in Maricopa County in each evaluation year assuming the continuation (without change) of current County fuel regulations. According to the SoW, "ADEQ shall provide the Contractor all necessary data relating to modeling assumptions, emissions inventories, and other information needed to characterize emissions in Maricopa County." This clause was interpreted to imply that not only should the local inventory data be provided by ADEQ (or their designee), but that all data provided should be used without change, except as necessary to conduct the required fuel analyses.

Table 5.5: Results of Diesel Engine Regression Analysis
(Revised October 2000)

Pollutant	r^2	Model Parameter					
		Intercept	Sulfur (wt.%)	Aromatics (vol.%)	Fraction of Aromatics that are Polycyclic	Relative Density	Cetane-30
HC (1)	*0.884*	0.949	--	-0.1922 *(-3.587)*	--	-4.518 *(-2.509)*	-0.783 *(-2.628)*
HC (2)	*0.829*	0.768	--	-0.0552 *(-0.905)*	+0.0488 *(0.801)*	--	-0.7735 *(-9.446)*
CO	*0.904*	0.839	--	+0.0079 *(2.303)*	--	--	-0.4165 *(-11.59)*
NO_x	*0.909*	0.6503	+0.00524 *(4.206)*	+0.0557 *(11.102)*	--	--	-0.04795 *(-7.208)*
PM (1)	*0.980*	-0.366	+0.009255 *(1.838)*	+0.1331 *(5.035)*	+0.0731 (3.810)	+1.785 (2.466)	-0.06326 *(-2.383)*
PM (2)	*0.979*	-0.3	+0.01563 *(2.353)*	+0.09134 *(4.074)*	+0.06594 *(3.384)*	--	-0.0674 *(-2.498)*

Equations designated as (1) represent the model of best statistical fit, while equations designated as (2) represent best engineering models. For this analysis, the best engineering models (2) were used for both HC and PM analysis.

The t statistics of model coefficients are indicated in parenthesis.

In some instances, emissions inventory data could not be provided for the evaluation years or pollutants specified in the SoW. In such cases, inventories were estimated from those provided for other years or constructed using standardized inventory development tools (e.g., MOBILE5a) and aggregate Maricopa County input data. In other instances, expansions of the provided inventory data were necessary to disaggregate particular source category emissions. For example, the provided emissions inventory data was not always disaggregated into its gasoline

Table 5.6: Fuel-Specific Emission Reductions (Percent)

Diesel Formulation Option	HC	CO	NO_x	PM
EPA Diesel, Cetane Enhanced	22.4 (22.6)	12.75	1.56	2.18 (2.05)
EPA Diesel, Low Sulfur + Cetane	21.9 (21.1)	12.83	2.55	4.33 (4.07
CARB Diesel, Formula (200 ppm)	18.4 (12.5)	13.7	7.29	11.96 (12.99)
CARB Diesel, Average Properties	36.1 (35.4)	22.8	5.60	8.7 (8.3)
Advanced Blend	47.0 (40.6)	31.3	9.11	14.05 (16.45)
Swedish Class 1	34.4 (3.0)	17.8	12.64	38.0 (42.1)

Numbers in parenthesis are based on best statistical models, all other numbers based on best engineering.

and diesel vehicle components. Finally, it was also necessary to adjust provided (or derived) baseline emissions inventory data to reflect actual Maricopa County baseline fuel quality. Such an adjustment is required to ensure that fuel formulation impacts are not over- or understated due to emissions differentials between the fuel assumptions used in the construction of the provided inventories and the actual fuels being sold in the County. These latter adjustments are described in Section 5.4.

Tables 5.7A through 5.7G summarize the baseline emission inventories used to support this analysis. These inventories do not reflect the baseline fuel adjustments noted above, but rather form the basis against which such adjustments were applied (see Section 5.4).

Summertime VOC, CO, and NO_x inventories were provided directly by ADEQ for both 1999 and 2010. The point, area, biogenic, on-road mobile, and off-road mobile estimates presented in Table 5.7A reflect those provided by ADEQ. The gasoline/diesel emissions split for off-road vehicles and engines was also provided directly by ADEQ, while the corresponding split for on-road vehicles was derived through MOBILE5a analysis using input data provided by ADEQ.

Table 5.7A: Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

			VOC (Mtpd) Summer 1999	VOC (Mtpd) Summer 2010	NO_x (Mtpd) Summer 1999	NO_x (Mtpd) Summer 2010	CO (Mtpd) Summer 1999	CO (Mtpd) Summer 2010
Point			15.0	18.0	23.0	24.0	3.0	17.0
Area			66.0	86.0	12.0	16.0	5.0	7.0
Biogenic			57.0	57.0	14.0	14.0	0.0	0.0
On-Road			103.0	75.0	194.0	221.0	1202.0	1017.0
	Gasoline		95.8	67.1	136.4	159.2	1146.2	943.7
		Exhaust	54.5	43.0	136.4	159.2	1146.2	943.7
		Evap	41.3	24.1	0.0	0.0	0.0	0.0
	Diesel		7.2	7.9	57.6	61.8	55.8	73.3
	Other		0.0	0.0	0.0	0.0	0.0	0.0
Off-Road			89.0	63.0	89.0	118.0	781.0	1090.0
	Gasoline		71.4	36.3	4.1	6.4	682.8	934.2
		Exhaust	41.4	17.6	4.1	6.4	682.8	934.2
		Evap	30.0	18.7	0.0	0.0	0.0	0.0
	Diesel		16.0	25.0	79.4	105.0	76.5	131.6
	Other		1.7	1.7	5.6	6.6	21.7	24.1
All Sources			330.0	299.0	332.0	393.0	1991.0	2131.0

(Mtpd indicates metric tons per day.)

Table 5.7B: Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

			CO (Mtpd) Winter 2001	CO (Mtpd) Winter 2010	VOC (Mtpd) Winter 2004	VOC (Mtpd) Winter 2010	NO_x (Mtpd) Winter 2004	NO_x (Mtpd) Winter 2010
Point			2.6	2.6	5.9	3.7	8.9	5.3
Area			8.8	10.3	70.0	79.9	12.8	14.7
Biogenic			0.0	0.0	57.3	60.6	14.1	14.9
On-Road			506.1	421.8	89.2	89.7	219.4	228.5
	Gasoline		475.3	389.0	80.1	79.1	161.9	169.3
		Exhaust	475.3	389.0	64.8	65.5	161.9	169.3
		Evap	0.0	0.0	15.3	13.6	0.0	0.0
	Diesel		30.8	32.8	9.1	10.6	57.6	59.2
	Other		0.0	0.0	0.0	0.0	0.0	0.0
Off-Road			134.0	173.6	15.8	18.7	27.9	32.4
	Gasoline		103.7	135.5	9.5	11.1	0.9	1.1
		Exhaust	103.7	135.5	7.2	6.3	0.9	1.1
		Evap	0.0	0.0	2.4	4.8	0.0	0.0
	Diesel		16.9	25.4	4.9	6.2	22.4	26.5
	Other		13.4	12.7	1.4	1.4	4.7	4.8
All Sources			651.5	608.2	238.3	252.7	283.1	295.8

(Mtpd indicates metric tons per day.)

Table 5.7C: Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

	Carbon PM-10 (Mtpy) Annual 2004	Carbon PM-10 (Mtpy) Annual 2010	SO_4 PM-10 (Mtpy) Annual 2004	SO_4 PM-10 (Mtpy) Annual 2010	NO_3 PM-10 (Mtpy) Annual 2004	NO_3 PM-10 (Mtpy) Annual 2010	Total PM-10 (Mtpy) Annual 2004	Total PM-10 (Mtpy) Annual 2010
Point	1177	1177	2664	2417	156	141	3997	3735
Area	25892	20922	2193	2530	128	148	28213	23600
On-Road Dust (Biogenic NO_3)	31799	38390	0	0	135	139	31934	38529
On-Road Combustion	1112	855	1554	1557	2012	2167	4678	4578
Gasoline	224	195	1135	1129	1463	1584	2822	2907
Exhaust	224	195	1135	1129	1463	1584	2822	2907
Evap	0	0	0	0	0	0	0	0
Diesel	888	660	419	428	549	583	1856	1671
Other	0	0	0	0	0	0	0	0
Off-Road Combustion	3939	5476	1897	2637	627	725	6462	8838
Gasoline	630	876	1077	1312	29	36	1736	2224
Exhaust	630	876	1077	1312	29	36	1736	2224
Evap	0	0	0	0	0	0	0	0
Diesel	3308	4600	820	1325	547	634	4675	6559
Other	0	0	0	0	52	55	52	55
All Sources	63918	66819	8307	9141	3059	3321	75284	79281

(Mtpy indicates metric tons per year.)

Table 5.7D: Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

	Carbon PM-2.5 (Mtpy) Annual 2004	Carbon PM-2.5 (Mtpy) Annual 2010	SO_4 PM-2.5 (Mtpy) Annual 2004	SO_4 PM-2.5 (Mtpy) Annual 2010	NO_3 PM-2.5 (Mtpy) Annual 2004	NO_3 PM-2.5 (Mtpy) Annual 2010	Total PM-2.5 (Mtpy) Annual 2004	Total PM-2.5 (Mtpy) Annual 2010
Point	650	650	2397	2175	125	113	3172	2939
Area	17171	13875	1974	2277	103	118	19248	16271
On-Road Dust (Biogenic NO_3)	10378	12529	0	0	108	111	10487	12641
On-Road Combustion	995	767	1399	1401	1609	1734	4003	3902
Gasoline	189	168	1022	1016	1170	1267	2381	2451
Exhaust	189	168	1022	1016	1170	1267	2381	2451
Evap	0	0	0	0	0	0	0	0
Diesel	806	600	377	385	439	466	1622	1451
Other	0	0	0	0	0	0	0	0
Off-Road Combustion	3534	4933	1707	2373	502	580	5743	7886
Gasoline	532	755	969	1181	23	29	1524	1965
Exhaust	532	755	969	1181	23	29	1524	1965
Evap	0	0	0	0	0	0	0	0
Diesel	3002	4178	738	1193	437	507	4177	5877
Other	0	0	0	0	41	44	41	44
All Sources	32729	32755	7477	8226	2447	2657	42652	43638

(Mtpy indicates metric tons per year.)

Table 5.7E: Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

	Carbon PM-10 (Mtpy) Winter 2004	Carbon PM-10 (Mtpy) Winter 2010	SO_4 PM-10 (Mtpy) Winter 2004	SO_4 PM-10 (Mtpy) Winter 2010	NO_3 PM-10 (Mtpy) Winter 2004	NO_3 PM-10 (Mtpy) Winter 2010	Total PM-10 (Mtpy) Winter 2004	Total PM-10 (Mtpy) Winter 2010
Point	3.2	3.2	7.3	6.6	0.1	0.1	10.6	9.9
Area	70.9	57.3	6.0	6.9	0.2	0.2	77.1	64.4
On-Road Dust (Biogenic NO_3)	87.1	105.2	0.0	0.0	0.2	0.2	87.3	105.4
On-Road Combustion	3.0	2.3	4.3	4.3	2.8	3.0	10.1	9.6
Gasoline	0.6	0.5	3.1	3.1	2.1	2.2	5.8	5.9
Exhaust	0.6	0.5	3.1	3.1	2.1	2.2	5.8	5.9
Evap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diesel	2.4	1.8	1.1	1.2	0.7	0.8	4.3	3.8
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Combustion	10.8	15.0	5.2	7.2	0.4	0.4	16.4	22.7
Gasoline	1.7	2.4	3.0	3.6	0.0	0.0	4.7	6.0
Exhaust	1.7	2.4	3.0	3.6	0.0	0.0	4.7	6.0
Evap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diesel	9.1	12.6	2.2	3.6	0.3	0.3	11.6	16.6
Other	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
All Sources	175.1	183.1	22.8	25.0	3.6	3.9	201.5	212.0

(Mtpy indicates metric tons per year.)

Table 5.7F Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

	Carbon PM-2.5 (Mtpy) Winter 2004	Carbon PM-2.5 (Mtpy) Winter 2010	SO_4 PM-2.5 (Mtpy) Winter 2004	SO_4 PM-2.5 (Mtpy) Winter 2010	NO_3 PM-2.5 (Mtpy) Winter 2004	NO_3 PM-2.5 (Mtpy) Winter 2010	Total PM-2.5 (Mtpy) Winter 2004	Total PM-2.5 (Mtpy) Winter 2010
Point	1.8	1.8	6.6	6.0	0.1	0.1	8.4	7.8
Area	47.0	38.0	5.4	6.2	0.1	0.2	52.6	44.4
On-Road Dust (Biogenic NO_3)	28.4	34.3	0.0	0.0	0.2	0.2	28.6	34.5
On-Road Combustion	2.7	2.1	3.8	3.8	2.2	2.4	8.8	8.4
Gasoline	0.5	0.5	2.8	2.8	1.7	1.8	5.0	5.0
Exhaust	0.5	0.5	2.8	2.8	1.7	1.8	5.0	5.0
Evap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diesel	2.2	1.6	1.0	1.1	0.6	0.6	3.8	3.3
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off-Road Combustion	9.7	13.5	4.7	6.5	0.3	0.3	14.7	20.4
Gasoline	1.5	2.1	2.7	3.2	0.0	0.0	4.1	5.3
Exhaust	1.5	2.1	2.7	3.2	0.0	0.0	4.1	5.3
Evap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diesel	8.2	11.4	2.0	3.3	0.2	0.3	10.5	15.0
Other	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
All Sources	89.7	89.7	20.5	22.5	2.9	3.1	113.0	115.4

(Mtpy indicates metric tons per year.)

Table 5.7G Baseline Modeling Inventories (Unadjusted for Actual Baseline Fuel Impacts)

	Benzene (Mtpd) Winter 2004	Benzene (Mtpd) Winter 2010	1,3-But (Mtpd) Winter 2004	1,3-But (Mtpd) Winter 2010	Formald (Mtpd) Winter 2004	Formald (Mtpd) Winter 2010	Acetald (Mtpd) Winter 2004	Acetald (Mtpd) Winter 2010	Total Toxics (Mtpd) Winter 2004	Total Toxics (Mtpd) Winter 2010
Point	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Area	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Biogenic	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
On-Road	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Gasoline	3.51	3.55	0.69	0.69	0.74	0.75	0.84	0.85	5.78	5.84
Exhaust	3.16	3.19	0.69	0.69	0.74	0.75	0.84	0.85	5.43	5.49
Evap	0.35	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.35
Diesel	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Other	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Off-Road	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Gasoline	0.39	0.34	0.08	0.07	0.09	0.08	0.10	0.09	0.67	0.59
Exhaust	0.35	0.31	0.08	0.07	0.08	0.07	0.09	0.08	0.60	0.53
Evap	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.06
Diesel	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
Other	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e	n/e
All Sources	3.90	3.89	0.77	0.77	0.83	0.83	0.95	0.94	6.45	6.43

"1,3-But" is 1,3-Butadiene
"Formald" is Formaldehyde
"Acetald" is Acetaldehyde

(Mtpy indicates metric tons per year.)
("n/e" indicates that no estimate is available for the applicable source category.)

For VOC, the split between exhaust and evaporative emissions was derived for on-road vehicles using the same MOBILE5a analysis. The evaporative/exhaust split for the off-road gasoline sector was derived using the corresponding splits presented in the 1996 MathPro summertime gasoline formulation analysis (*Assessment of Fuel Formulation Options for Maricopa County*, MathPro, Inc., November 7, 1996), but adjusted to reflect the off-road emissions inventory revisions implemented during the Voluntary Early Ozone Plan 1997 Reanalysis (*Reanalysis of the Metropolitan Phoenix Voluntary Early Ozone Plan (VEOP)*, ENSR, October 1997)

The wintertime CO inventories presented in Table 5.7B, were derived from wintertime CO inventory data provided by the Maricopa Association of Governments (MAG) for calendar years 1994, 2000, and 2010. The data provided by MAG was applicable to a mid-December modeling date and, therefore, the MAG 2000 inventory was equivalent to the January 1, 2001 inventory required for this analysis and was used directly. The mid-December 2010 MAG inventory was adjusted by one year to obtain data applicable to a January 1, 2010 modeling date. For major source categories, this adjustment was based on interpolation between the MAG-provided 2001 and 2010 inventories. On-road vehicle gasoline/diesel splits were derived through a MOBILE5a analysis using input data provided by MAG. Off-road splits were obtained by interpolating between the off-road splits provided by MAG for the 2001 and 2010 inventories.

The wintertime VOC and NO_x inventories presented in Table 5.7B were derived by adjusting the summertime VOC and NO_x inventories presented in Table 5.7A using relationships estimated from the provided summertime and wintertime CO inventories and MOBILE5a analysis. This inventory construction was required because no specific wintertime VOC or NO_x inventory data could be provided by either ADEQ or MAG. With the exception of area and on-road mobile sources, wintertime VOC and NO_x inventories were estimated by multiplying summertime emissions by a summertime-to-wintertime factor derived as the ratio of wintertime CO to summertime CO (and correcting for inventory geographic differences using provided VMT estimates as a surrogate for domain size impacts). For area sources, the bulk of VOC emissions were presumed to be evaporative in nature and constant across seasons. Seasonal correction factors for on-road mobile emissions of both VOC and NO_x were derived through wintertime versus summertime MOBILE5a analysis.

All PM inventories were derived from: (1) an annual 2006 PM-10 inventory provided by MAG, (2) a 1994 PM-10 inventory provided by ADEQ (but developed by MAG in 1997), (3) PM-10 growth factors for 2001 and 2010 as provided by ADEQ (from the same 1997 MAG PM analysis), and (4) PM-10 to PM-2.5 ratios developed from 1994 inventory relations provided by MAG. PM-10 inventories for the 2004 and 2010 evaluation years required under the SoW were derived by converting the 2001 and 2010 PM-10 growth factors into annual growth rates which were subsequently applied to the provided 2006 PM-10 inventory to generate 2004 and 2010 emission estimates. For off-road vehicles and engines, gasoline/diesel splits provided by MAG for 2006 were used without change for 2004 and 2010. For on-road vehicles, splits were based on PART5 analysis using input data provided by MAG. PM-2.5 inventories were then developed by applying factors derived from the relationship between MAG's 1994 PM-2.5 and PM-10 inventories. The resulting data are presented under the heading "Carbon (short for carbonaceous) PM" in Tables 5.7C and 5.7D.

In discussing the provided 2006 PM inventory with MAG, it became clear that the data did not reflect either primary or secondary sulfate or nitrate PM. Therefore, these inventories were developed separately. For nitrate PM, no estimate for primary emissions was undertaken due to time constraints and lack of readily available data. Secondary nitrate PM inventories were derived from the summer and winter NO_x inventories discussed above and an assumption that 2 percent of emitted NO_x subsequently reacts in the atmosphere to form nitrate PM. It was further assumed that 98 percent of the nitrate PM is PM-10 and 80 percent is PM-2.5. Each of these constants was derived from previous analysis undertaken by EEA for the EPA (*A Review of Primary and Secondary Particulate Matter Associated with Light-Duty Vehicles: Task 3 Draft Report*, Energy and Environmental Analysis, Inc., August 1997)

Primary and secondary sulfate PM inventories were estimated for on- and off-road vehicles through PART5 analysis using MAG-provided input data. The ratio of PART5-predicted primary sulfate and gaseous SO_2 emissions to primary carbonaceous PM was applied to the MAG provided carbonaceous PM estimates to derive Maricopa-adjusted sulfate and SO_2 emissions inventories. For off-road vehicles, non-catalyst on-road impacts were utilized. For other source categories, direct sulfate PM emissions were presumed to be zero and SO_2 emissions were estimated by applying national average SO_2 to NO_x emission ratios to Maricopa County NO_x inventories. Secondary sulfate PM emissions were estimated directly from the derived SO_2 inventories by assuming that: (1) 12 percent of SO_2 is subsequently converted to sulfate PM, (2) 98 percent of sulfate PM is PM-10, and (3) 90 percent of sulfate PM is PM-2.5. The 12 percent sulfate conversion fraction is taken directly from the default assumptions inherent in PART5, while the PM-10 and PM-2.5 fractions come from the same EEA secondary particulate analysis document used to derive nitrate PM fractions. That same secondary particulate analysis provides some indication that the EPA-derived 12 percent sulfate conversion fraction may be understated by a factor of 2 or more. Given the lack of Maricopa County-specific data upon which to base a revision to the PART5-assumed 12 percent value, no change was implemented for this analysis. Nevertheless, it should be recognized that fuel-specific PM impacts may be similarly understated should the true conversion fraction be larger. The total PM-10 and PM-2.5 inventories for this analysis are taken as the sum of the carbonaceous, sulfate, and nitrate PM estimates presented in Tables 5.7C through 5.7F.

For gasoline-related PM analysis, seasonal (i.e., wintertime) PM inventories are required since the fuel will not be available year-round. Since no seasonal PM inventory relations were provided by either ADEQ or MAG, no seasonal variation in either carbonaceous or sulfate PM was assumed. The daily PM inventories presented in Tables 5.7E and 5.7F simply reflect ($1/365^{th}$) of the presented annual inventories. The only exception is for secondary nitrate PM. Since nitrate PM emission estimates are based on provided NO_x inventories, a seasonal adjustment was implemented on the basis of an equal weighting of summertime and wintertime emission profiles.

Table 5.7G presents the HAP's inventories used for this analysis. Each of the presented inventories was constructed using EPA Complex Model relations since no Maricopa County-specific data was provided by either ADEQ or MAG. The Complex Model predicts HAP's emission rates as well as total VOC emission rates and the ratio of these Complex Model estimates was applied to the Maricopa County-specific VOC inventories to derive HAP's inventories for both on- and off-road *gasoline* vehicles and engines. HAP's inventories for other source categories were not derived due to time and data constraints.

5.4 Baseline Inventory Adjustments

In developing inventories, local air quality planners generally only consider local baseline fuel properties at the level of detail recognized by the applicable inventory modeling tool (i.e., MOBILE5a or PART5). To the extent that actual baseline fuel quality in Maricopa County differs *from that assumed by these emissions inventory models*, the calculated emission inventories may need to be adjusted to reflect actual baseline fuel quality. Both the MOBILE5a and PART5 models used to develop the Maricopa County baseline emissions inventories presented in Section 5.3 assume the applicability of national average gasoline fuel qualities (excepting, in the case of MOBILE5a, an allowance for local fuel oxygen and RVP). The main issue associated with such an assumption is that actual Maricopa County fuel sulfur levels are far below those assumed in either PART5 (340 ppm by weight, or ppmW) or MOBILE5a (338 ppmW in the wintertime, 339 ppmW in the summertime). Since vehicle emissions are *very* sensitive to fuel sulfur content, adjusting the modeling inventories developed on the basis of ≅340 ppmW sulfur fuel to reflect the very low sulfur contents of the fuel options (both gasoline and diesel) evaluated in this analysis would overstate their emission reduction effectiveness.

To accurately assess the impact of alternative fuel formulations, the baseline inventories presented in Section 5.3 must be adjusted to reflect emissions expected from actual Maricopa County baseline fuel (rather than a hypothetical modeling baseline fuel). To undertake this adjustment, the properties of Maricopa County baseline diesel fuel and wintertime gasoline for each of the evaluation years was estimated, as previously presented in Section 2. The emissions impacts of these "actual" baseline fuels relative to the *modeling* baseline fuels was estimated using the exact same modeling methods described in Section 5.2 for the alternative fuel options and the resulting impacts were applied to the modeled emissions inventories presented in Section 5.3 to derive the adjusted baseline inventories against which alternative fuel formulation impacts can be properly assessed. A wintertime evaporative VOC adjustment was estimated because the MAG-provided wintertime inventories were modeled on the basis of a 9.0 psi RVP gasoline, whereas the actual baseline RVP level (as well as the RVP level of all alternative gasoline formulations) is assumed to be 8.7 psi. The resulting estimated baseline inventory adjustments are presented in **Tables 5.8A and 5.8B**. These adjustments were applied directly to the emissions estimates presented in Tables 5.7A through 5.7G, as applicable, *prior to* evaluating alternative fuel option impacts.

There are two specific issues of importance in considering these baseline fuel adjustments. First, it is not clear to what extent these adjustments do or do not affect attainment planning processes in Maricopa County. It is our understanding that even though baseline modeling inventories were not adjusted for actual Maricopa County fuel quality, the subsequent calibration of airshed model performance to locally measured ambient air quality readings is assumed to implicitly incorporate this (as well as any other necessary) inventory adjustments. Therefore, it is further assumed that the attainment target level of emissions is not affected by this adjustment. However, it is not completely clear that the airshed models used for attainment demonstration purposes can be assumed to behave in the linear fashion necessary to completely nullify the need for the explicit baseline fuel adjustment in determining attainment emissions targets.

The second issue for consideration is that the adjustments presented in Tables 5.8A and 5.8B reflect a movement from a hypothetical modeling fuel (which was never sold in Maricopa County) to a baseline fuel expected to be sold in the evaluation year under consideration. These adjustments do *not* reflect the differentials between *current* (i.e., 1997) Maricopa County fuels and fuels expected to be sold in the evaluation years. The differential between current Maricopa County fuels and expected future baseline fuels is only a fraction of the total adjustment. In other words, the emissions differentials between current and future Maricopa County fuels are much smaller than the differentials between the MOBILE5a and PART5 baseline fuels and current Maricopa County fuels. While current Maricopa County fuel quality was not evaluated in this analysis, it is estimated that essentially 100 percent of the estimated diesel fuel adjustment and 80 percent of the estimated gasoline adjustment is associated with the difference between the hypothetical modeling fuel assumptions and *current* fuel quality. Therefore, only about 20 percent of the baseline gasoline adjustment is reflective of emission reductions which can *actually* be expected to accrue over the next several years.

Table 5.8A: Inventory Adjustments to Account for Baseline Fuel Qualities

Pollutant	Season	Evaluation Year	On-Road Vehicles Gasoline Exhaust	On-Road Vehicles Gasoline Evap	On-Road Vehicles Diesel	Off-Road Vehicle/Engines Gasoline Exhaust	Off-Road Vehicle/Engines Gasoline Evap	Off-Road Vehicle/Engines Diesel
VOC	Summer	1999	0	0	0	0	0	0
VOC	Summer	2010	0	0	0	0	0	0
VOC	Winter	2004	3.73	0.67	0	0.13	0.16	0
VOC	Winter	2010	3.77	0.90	0	0.11	0.34	0
NO_x	Summer	1999	0	0	0	0	0	0
NO_x	Summer	2010	0	0	0	0	0	0
NO_x	Winter	2004	12.03	0	0	0.01	0	0
NO_x	Winter	2010	12.78	0	0	0.01	0	0
CO	Summer	1999	0	0	0	0	0	0
CO	Summer	2010	0	0	0	0	0	0
CO	Winter	2001	40.66	0	0	-0.57	0	0
CO	Winter	2010	33.58	0	0	-0.74	0	0
Carbon PM-10	Annual	2004	n/e	n/e	7	n/e	n/e	26
Carbon PM-10	Annual	2010	n/e	n/e	5	n/e	n/e	37
SO_4 PM-10	Annual	2004	n/e	n/e	243	n/e	n/e	475
SO_4 PM-10	Annual	2010	n/e	n/e	248	n/e	n/e	769
NO_3 PM-10	Annual	2004	n/e	n/e	0	n/e	n/e	0
NO_3 PM-10	Annual	2010	n/e	n/e	0	n/e	n/e	0
Total PM-10	Annual	2004	n/e	n/e	250	n/e	n/e	502
Total PM-10	Annual	2010	n/e	n/e	253	n/e	n/e	805
Carbon PM-2.5	Annual	2004	n/e	n/e	6	n/e	n/e	24
Carbon PM-2.5	Annual	2010	n/e	n/e	5	n/e	n/e	33
SO_4 PM-2.5	Annual	2004	n/e	n/e	218	n/e	n/e	428
SO_4 PM-2.5	Annual	2010	n/e	n/e	223	n/e	n/e	692
NO_3 PM-2.5	Annual	2004	n/e	n/e	0	n/e	n/e	0
NO_3 PM-2.5	Annual	2010	n/e	n/e	0	n/e	n/e	0
Total PM-2.5	Annual	2004	n/e	n/e	225	n/e	n/e	452
Total PM-2.5	Annual	2010	n/e	n/e	228	n/e	n/e	725

(1) Summertime and wintertime seasonal adjustments are in metric tons per day.
(2) Annual adjustments are in metric tons per year.
(3) "n/e" indicates that no estimate was derived.

Table 5.8B: Inventory Adjustments to Account for Baseline Fuel Qualities

			On-Road Vehicles			Off-Road Vehicle/Engines		
Pollutant	Season	Evaluation Year	Gasoline Exhaust	Gasoline Evap	Diesel	Gasoline Exhaust	Gasoline Evap	Diesel
Benzene	Winter	2004	0.635	0.169	n/e	0.040	0.019	n/e
Benzene	Winter	2010	0.642	0.171	n/e	0.035	0.016	n/e
1,3-Butadiene	Winter	2004	0.082	0	n/e	0.008	0	n/e
1,3-Butadiene	Winter	2010	0.083	0	n/e	0.007	0	n/e
Formaldehyde	Winter	2004	0.006	0	n/e	0.001	0	n/e
Formaldehyde	Winter	2010	0.006	0	n/e	0.001	0	n/e
Acetaldehyde	Winter	2004	0.082	0	n/e	0.004	0	n/e
Acetaldehyde	Winter	2010	0.083	0	n/e	0.004	0	n/e
Total Toxics	Winter	2004	0.805	0.169	n/e	0.053	0.019	n/e
Total Toxics	Winter	2010	0.814	0.171	n/e	0.047	0.016	n/e
Carbon PM-10	Winter	2004	0.03	0	n/e	0.03	0	n/e
Carbon PM-10	Winter	2010	0.02	0	n/e	0.04	0	n/e
SO4 PM-10	Winter	2004	1.33	0	n/e	1.90	0	n/e
SO4 PM-10	Winter	2010	1.32	0	n/e	2.32	0	n/e
NO3 PM-10	Winter	2004	0.15	0	n/e	0.00	0	n/e
NO3 PM-10	Winter	2010	0.17	0	n/e	0.00	0	n/e
Total PM-10	Winter	2004	1.51	0	n/e	1.93	0	n/e
Total PM-10	Winter	2010	1.51	0	n/e	2.36	0	n/e
Carbon PM-2.5	Winter	2004	0.02	0	n/e	0.03	0	n/e
Carbon PM-2.5	Winter	2010	0.02	0	n/e	0.04	0	n/e
SO4 PM-2.5	Winter	2004	1.19	0	n/e	1.71	0	n/e
SO4 PM-2.5	Winter	2010	1.19	0	n/e	2.09	0	n/e
NO3 PM-2.5	Winter	2004	0.12	0	n/e	0.00	0	n/e
NO3 PM-2.5	Winter	2010	0.14	0	n/e	0.00	0	n/e
Total PM-2.5	Winter	2004	1.34	0	n/e	1.74	0	n/e
Total PM-2.5	Winter	2010	1.34	0	n/e	2.12	0	n/e

(1) Summertime and wintertime seasonal adjustments are in metric tons per day.
(2) Annual adjustments are in metric tons per year.
(3) “n/e” indicates that no estimate was derived.

6. RESULTS AND FINDINGS

This section presents the primary results and findings of our analysis of the gasoline and diesel fuel formulations described in Section 1. The discussion is in eight parts:

1. Interpreting the quantitative results
2. Results and findings of the *distribution* analysis
3. Results and findings of the *refining* analysis
4. Results and findings of the *emissions* analysis
5. Estimated *cost-effectiveness* of the various fuel formulations
6. Earliest availability of the various fuel formulations
7. Supply of diesel fuel to areas outside of Maricopa County
8. Additional considerations

The second, third, and fourth parts lay out the primary results of the separate phases of our analysis. The fifth part ties the results together, in terms of the cost-effectiveness ($K/ton of emissions reduction), total cost, and total emissions reduction associated with the fuel formulations. The last three parts address policy-related issues.

In the discussion that follows, and in all of the associated tables and exhibits, we use the abbreviated names for the fuel formulation options, defined in Section 1.2.

6.1 Interpreting Quantitative Results of the Analysis

This discussion is taken, with only slight changes, from [Ref. 1].

We think it essential, before presenting quantitative results, to briefly discuss the nature and proper use of results from analytical studies such as this one. One should have modest expectations about the precision of these results or the likelihood that they "predict" future conditions. Rather, one should view them as reliable and robust indicators of the relative merits of the various options, with respect to the magnitude of their relative costs, emissions benefits, and cost-effectiveness.

Our technical approach was as comprehensive and rigorous as tight limits on time and resources permitted. Nonetheless, uncertainties abound in the nature of the phenomena that we analyzed, the assumptions and the data available for the analysis, and the predictive capabilities of the available mathematical models. In particular, we note uncertainties in estimating (1) baseline emissions inventories; (2) on-road and off-road consumption of diesel fuel in Maricopa County; (3) CO emissions of gasoline vehicles and PM, NOx, and CO emissions of diesel vehicles, as functions of fuel properties; and (4) costs of the diesel fuel formulations.

This analysis points to the future: 1999 through 2010. There are no facts about the future. So, analysts make assumptions about future conditions – crude oil prices, oxygenate prices, gasoline and diesel fuel demand, emissions inventories, vehicle miles traveled, vehicle fleet configurations, and a host of other technical and economic factors. Different sets of assumptions lead to different absolute results. For example, the most important determinant of the cost of producing gasoline and diesel fuel is the price of crude oil.

Our mathematical models are very good, but like all models, they are approximations of certain parts of the real world. Even if we had "perfect" assumptions going in, the results coming out would not be perfect predictors of the future.

In addition, with the same set of assumptions and the same models, the results of an analysis can depend on the details of the methodology and on the analysts' skill and judgement.

But, rigorous quantitative analysis is the best method available for assessing complex policy issues, especially those involving the interplay of technical and economic driving forces. More importantly, in such situations, rigorous analysis can structure the problem for policy-makers and yield reliable and robust assessments of the relative merits of different policy options.

Analyses such as this one give consistent treatment to all the options under consideration and focus on comparative (or relative) results – similarities and differences between options – rather than on absolute results or forecasts. Experience shows that the important differences between options and the important (qualitative) characteristics of individual options usually survive changes in primary assumptions.

> Thus, even if the price of crude oil were to double or the baseline emission inventories were revised substantially, the rank ordering of the various fuel formulations with respect to cost effectiveness would likely not change (even though the absolute cost of fuel production and the abolute volumes of emissions reductions would change a lot).

The results of this study should be viewed as robust indicators of the relative costs and benefits of the various fuel formulations (and not as precise assertions of costs, benefits, or cost-effectiveness). In a study such as this one, it's better to be approximately right than precisely wrong. We think the results of this study are approximately right.

6.2 The Gasoline and Diesel Fuel Distribution System

Analysis of the gasoline and diesel fuel distribution system (encompassing the refineries, the SFPP South Pipeline System, and the local bulk terminals) leads to these findings:

6.2.1 Pipeline Throughput and Capacity

In 1997, the SFPP West and East pipeline systems delivered these volumes to the Phoenix area:

	Total Volume (K Bbl/day)	% Shares West	% Shares East
? Gasoline	82.6	70%	30%
? EPA diesel fuel	27.4	88%	12%
? Off-road diesel fuel	1.1	0	100%

At present, the West pipeline's Colton-to-Phoenix segment operates at about 95% of its capacity (≈ 175 M Bbl/day), on average, and at 100% capacity during certain periods. The East pipeline's Tucson-to-Phoenix segment operates at about 70% of its capacity (≈ 55 M Bbl/day).

6.2.2 Gasoline Supply

The existing distribution system is now supplying to Maricopa County, in routine operations, special gasolines – in particular, CBG gasolines – as opposed to conventional gasolines meeting state-wide standards. Hence, the existing distribution system has the capability to deliver required volumes of any of the proposed gasoline formulations (or other formulations, whether produced to property-based or performance-based standards) – even though these gasolines are not the same as those supplied to the rest of the state.

The difference between CBG (Maricopa County) and conventional (state-wide) gasoline standards leads to some spill-over and local give-away of "excess quality" in Maricopa County and adjoining areas. (Spill-over and give-away are described and analyzed in detail in [Ref. 1, Section 3], with respect to gasoline supplied to Maricopa County. The essentials of that analysis are applicable to diesel fuels as well.)

For any of the gasoline formulations considered in this study, the spill-over volume and costs would be about the same as for baseline gasoline (i.e., with business-as-usual). That is, none of the gasoline formulations would lead to a significant increase in spill-over cost.

6.2.3 Diesel Fuel Supply

The West pipeline system – but not the East – has facilities in place to deliver CARB diesel fuel to the Phoenix area (along with EPA diesel and off-road diesel fuel), but not any of the other diesel fuel formulations. The other proposed diesel fuel formulations would constitute an additional grade in the distribution system. Handling an additional grade would call for some capital investment (e.g., additional tankage at refineries, along the pipeline, and/or at terminals).

The investment and corresponding per-gallon capital charges would be the same for all the diesel fuel formulations, other than the CARB diesels.

6.3 Costs and Physical Properties of the Gasoline and Diesel Fuel Formulations

Tables 6.1 and **6.2** (next two pages) show the primary results of the refining analysis, for the gasoline and diesel fuel formulations, respectively.

Appendix B shows detailed results of the refinery LP modeling, by which we estimated costs and properties of the gasoline formulations. **Exhibits B.1.1 – B.1.4** and **B.2.1 - B.2.4** (in Appendix B) provide detailed results of the refining analysis for, respectively, the East and West notional refineries. Each exhibit covers all of the gasoline formulation options considered. The contents of the exhibits are as follows.

- Exhibits B.x.1: Estimated costs of the gasoline formulations and investment requirements for the refinery aggregates
- Exhibits B.x.2: Crude oil inputs, process unit utilization, capacity additions, and refinery operations for the gasoline formulations
- Exhibits B.x.3: Properties and compositions of the gasoline formulations
- Exhibits B.x.4: Crude oil inputs, other inputs, and refined product outputs of the notional refinery, for each gasoline formulation

Here, **x** denotes the numbers **1** or **2**, corresponding to the **East** and **West** refineries, respectively.

6.3.1 Gasoline Formulations

The estimated costs and properties shown in Table 6.1 are volume-weighted averages of gasoline supplies from the West and East refining centers, weighted by their volume shares in 1997 (as shown in Sections 3.1 and 6.2).

Production Costs

The top portion of Table 6.1 summarizes the estimated economics of the gasoline formulations considered. For each, the total average cost (in ¢/gal) is the sum of

Table 6.1: Summary of Results of the Refining Analysis: Gasoline Formulations

		Gasoline Formulations				
	Units	**G1**	**G2**	**G3**	**G4**	**G5**
Total Average Cost	¢/gal	1.3	4.8	9.7	8.3	6.2
Operating cost		0.6	2.2	7.2	5.0	2.9
Capital charge		0.6	2.4	2.6	2.5	2.8
Ancillary cost						
Mileage loss		0.1	0.2	-0.2	0.7	0.5
Physical Properties						
RVP	Psi	8.7	8.7	8.7	8.7	8.7
Oxygen content	Wt.%	3.5	3.5	1.9	3.5	3.5
Sulfur content	Ppm	80	30	20	20	24
Aromatics content	Vol.%	27.6	25.7	23.0	23.0	24.0
Benzene content	Vol.%	0.96	0.96	0.56	0.56	0.96
Olefins content	Vol.%	10.2	9.2	3.9	3.9	6.1
E200	Vol.%	51.5	52.5	53.2	54.4	52.9
E300	Vol.%	88.7	88.2	88.8	88.9	87.8
Fuel Economy						
Energy density	MM BTU/ Bbl	5.041	5.037	5.060	5.009	5.020
Δ Energy density	**%**	-0.16	-0.24	+0.22	-0.79	-0.57

Gasoline Formulations:

G1. CBG Type 1 (≈ Fed RFG2) with ≤ **80** ppm sulfur (season average)

G2. CBG Type 1 (≈ Fed RFG2) with ≤ **30** ppm sulfur (season average)

G3. CBG Type 2 (CARB RFG2) with **2.0** wt.% oxygen

G4. CBG Type 2 (CARB RFG2) with **3.5** wt.% oxygen

G5. CO Performance Standard Gasoline

Table 6.2: Summary of Results of the Refining Analysis: Diesel Fuel Formulations

Property	Units	Diesel Fuel Formulations D1	D2	D3	D4	D5	D6
Total Average Cost	¢/gal	1½	4	12½	5	9	35
Refining cost		1½	3½	10	4	6	32
Mileage loss			½	2½	1	3	3½
Physical Properties							
Sulfur content	Ppm	210	100	500	140	93	10
Aromatics content	Vol.%	29.1	26.0	10.0	18.2	12.1	5.0
PolyArom content	Wt.%	4.5	---	1.4	2.8	1.9	0.02
Cetane number		47.9	47.9	48	53.8	61.2	50
Specific gravity		0.856	0.85	0.83	0.842	0.82	0.81
T_{10}	^oF	446	440	430	440	450	---
T_{50}	^oF	525	520	510	531	535	---
T_{90}	^oF	611	605	600	623	630	550
Fuel Economy							
Energy density	MM BTU/ Bbl	5.460	5.436	5.355	5.412	5.335	5.260
Δ Energy density	**%**	0	-0.44	-1.92	-0.88	-2.29	-3.66

Diesel Fuel Formulation:

D1. Baseline EPA Diesel, Cetane Enhanced (+ **5** cetane numbers)

D2. Baseline EPA Diesel, Cetane Enhanced and **100** ppm sulfur

D3. CARB Diesel - Formula Properties with **200** ppm sulfur

D4. CARB Diesel - Average Properties of Certified Formulations

D5. Advanced Blend (CARB diesel and Fischer-Tropsch distillate)

D6. Swedish Class 1 Diesel

- Incremental (direct) refinery operating costs incurred in producing the formulation
- Capital charges for investments in refining capacity needed to produce the formulation
- Ancillary refining costs incurred in producing the formulation (e.g., additional tankage, higher safety margins, reduced flexibility, etc.)[6]
- The fuel economy (mileage) loss associated with the formulation options

All of these cost elements are relative to those of the baseline gasoline, whose average properties are shown in Table 2.1.

Table 6.1 and the various exhibits in Appendix B indicate the following economic findings.

- The CBG Type 2 options – **G3** and **G4** – have the highest incremental cost. The CBG Type 1 options – **G1** and **G2** – have the lowest incremental cost. **G1** is clearly the lowest cost option.

  The CBG Type 2 formulations (CARB RFG2) are more costly to produce than the CBG Type 1 formulations (fed RFG2) because of the stringent controls on aromatics content, benzene content, olefins content, and distillation in the CARB RFG2 standard.

- On the whole, the West refineries would have relatively high costs for **G3** and **G4**. These options involve increasing total production of CARB RFG2, and the California refineries have little spare capacity for producing CARB RFG2. Therefore, these options would incur high marginal costs of production.

- As a group, the East refineries incur higher per-gallon and higher investment costs than the West refineries to produce the various gasoline options. To produce **G3**, **G4**, **G5**, and **G6**, the East refineries would incur costs roughly double those of the West refineries.

  This difference exists because the East refineries are less "complex" (i.e., have less gasoline-making capability and less upgrading capacity per barrel of crude run) than the West refineries.

- The West and East refiners would have significantly different requirements for capital investment to produce the various gasoline formulations.

6 Our definition of ancillary costs is spelled out in [Ref. 11].

-- The East refiners would have the larger investment requirement and would have to make some investments for all of the gasoline formulation options.

-- The West refiners would have no investment requirement for **G1** and **G2**. They would have to invest for **G3** and **G4** to upgrade much of their remaining conventional gasoline out-turn to CARB RFG2.

- All of the gasolines but **G1** have low sulfur content (in the range of 20-30 ppm, average). **G1** (by definition) has average sulfur content of 80 ppm.

- All of the gasolines but **G3** contain 3.5 wt.% oxygen, achieved through ethanol blending at the terminals. **G3** (by definition) contains 2.0 wt.% oxygen, achieved through MTBE blending at the refineries.

In most cases, the indicated investments reflect expansions of existing process units or construction of secondary facilities (such as fractionators). In practice, refiners might choose not to make these investments, but rather modify operating procedures, use spare capacity elsewhere, or purchase blendstocks.

The refinery investment requirements shown in Exhibits B.1.1 and B.2.1 apply to the indicated refining *aggregates*, not to the notional refineries modeled in the analysis. That is, we scaled up the computed investment requirement for each notional refinery to the entire refining aggregate that it represented. So, the indicated investment estimates do not imply that every refiner in the given refining center would necessarily commit investment funds on a pro rata basis or make the same investment decisions.

Fuel economy

Fuel economy, or mileage (miles/gal), losses are social costs associated with the various fuel formulation options. As Table 6.1 shows, all of the gasoline formulations except **G3** incur a loss in fuel economy. For some of the gasoline formulations (e.g., **G4**), the mileage losses are significant contributors to the total social cost.

Physical considerations dictate that a gasoline's energy density – and hence fuel economy – decreases with increasing oxygen content, increasing distillation values (i.e., E200 and E300), and increasing RVP. The ARMS model captures all of these effects. We computed the mileage losses shown in Table 6.1 from energy density values produced by ARMS for each fuel formulation option, according to the formula shown in Section 4.2.

The primary cause of the mileage losses shown in Table 6.1 is increases in E200 and E300. These increases are a secondary consequence of sulfur control in the production of **G1**, **G2**, and **G5** and an on-purpose change in **G3** and **G4** induced by the CARB Predictive Model.

Physical Properties

The gasoline properties shown in Table 6.1 are volume weighted averages of contributions from the various refining aggregates. They are *average* properties (in the gasoline blending sense). That is, they correspond to averaging rather than per-gallon standards.

These gasoline properties were direct input to the emissions analysis (discussed in Section 5). The estimated emissions reductions shown in Section 6.4 apply to Maricopa County gasoline pools with these average properties.

6.3.2 Diesel Fuel Formulations

Technical uncertainties and lack of time precluded the use of refinery LP modeling to analyze the diesel fuel formulation. Hence, the estimated costs and properties for the diesel fuel formulations, shown in Table 6.2, are based on engineering analysis (discussed in Section 4.2).

Production Costs

The top portion of Table 6.2 summarizes the estimated economics of the diesel fuel formulations considered. For each diesel fuel formulation, the total average cost (in ¢/gal) is the sum of a refining cost (including incremental operating costs and capital charges) and mileage loss.

The estimates in Table 6.2 indicate the following economic findings.

- The **D1** formulation – involving only use of a cetane enhancer – is clearly the least cost option. The **D2** and **D4** formulations are next in terms of increasing cost, followed by **D5** and **D3**. The **D6** formulation, as expected, is in a class by itself when it comes to cost.

- Neither the **D5** nor the **D6** formulation is produced in the U.S. at present; only small volumes of **D3** are produced. Hence, our estimates of the economics of these options are subject to more uncertainty than our estimates for **D1**, **D2**, and **D4**.

- Except for **D1**, all of the diesel fuel formulations would require capital investment (for sulfur and aromatics control), in both the West and East refining centers.

Because of differences in refinery complexity, discussed in Section 6.3.1, the required investment per daily barrel of diesel fuel product would be higher in the East refining center than in the West.

As with investments for producing the gasoline formulations, refiners in a given refining center would not necessarily make investments on a pro rata basis or in a uniform fashion with respect to technology.

Fuel economy

As Table 6.2 shows, all of the diesel fuel formulations except **D1** incur a loss in fuel economy. For some of the diesel fuel formulations (**D3**, **D5**, and **D6**), the mileage losses are significant – in both absolute magnitude and as a contribution to the total social cost.

Physical considerations dictate that a diesel fuel's energy density – and hence fuel economy – decreases with decreasing density (or increasing API gravity), decreasing distillation temperatures (i.e., T_{10}, T_{50}, and T_{90}), and decreasing aromatics content. These properties are, to some extent, co-linear.

The primary causes of the mileage losses shown in Table 6.2 are decreases in specific gravity and distillation temperatures, relative to those of the baseline diesel fuel. These decreases are secondary consequences of desulfurization in the production of all of the diesel fuel formulations except **D1**.

Physical Properties

The diesel fuel properties shown in Table 6.2 are *average* properties (in the gasoline blending sense). That is, they correspond to averaging rather than per-gallon standards.

These diesel fuel properties were direct input to the emissions analysis (discussed in Section 5). The estimated emissions reductions shown in Section 6.4 apply to Maricopa County diesel fuel pools with these average properties.

6.4 Vehicle and Off-Road Emission Reductions of Gasoline and Diesel Fuel Formulations

As called for by the SoW, emissions impacts were determined for both gasoline and diesel fuel formulations. **Tables 6.3A** and **6.3B** summarize the results of the gasoline formulation emissions analysis. **Tables 6.4A** and **6.4B** summarize the corresponding results for the diesel fuel formulation analysis. Tables 6.3 and 6.4 present combined on- and off-road vehicle/engine impacts. **Appendix G** presents a detailed listing of emission reduction impacts for on-road and off-road sectors separately.

6.4.1 Gasoline Formulations

Tables 6.3A and 6.3B present the mass emission reductions estimated for each of the wintertime gasoline options. The specific calendar years evaluated are those cited in the SoW. Pollutants impacts related to PM planning were evaluated for calendar years 2004 and 2010. Pollutants related to CO planning (i.e. only CO) were evaluated for calendar years 2001 and 2010.

Since the gasoline formulation options are limited to wintertime-only sales, wintertime pollutant impacts are of specific concern. Exceedances of the CO NAAQS are a wintertime problem and, therefore, gasoline option impacts on CO are of primary importance. As indicated in Tables 6.3A and 6.3B, the **G4** formulation produces the greatest CO emission reductions. Two other formulations, **G2** and **G5**, also produce significant, albeit lesser, reductions. The **G1** and **G3** formulations produce the least significant CO reductions**.**

Particulate impacts are of year-round importance and thus the wintertime gasoline formulations are of significance to the PM planning process, but only in the context of reductions during the wintertime period. Although there is less difference in the PM impacts of the five formulations than is observed for CO, the **G4** formulation again produces the greatest estimated reductions for both PM-10 and PM-2.5. The **G2**, **G3**, and **G5** formulations produce similar but slightly smaller reductions. Only **G1** produces significantly smaller reductions.

The particulate impacts of the evaluated gasoline formulations consider both primary and secondary (sulfate and nitrate) PM impacts. The PM reductions of all five gasoline formulations are dominated by reductions in sulfate PM, driven by reductions in fuel sulfur content. Sulfate PM reductions account for over 90% of total estimated PM impact for all gasoline formulations.

Secondary organic PM impacts were not quantified since there is no reliable estimate for the fraction of VOC that is converted to organic PM in Maricopa County. Moreover, there is no tool available to accurately estimate the impact of changes in fuel formulation on this (unknown) secondary organic conversion rate. Generally, however, olefinic and aromatic VOC tend to be more effective producers of secondary organic PM. Therefore, gasoline formulations which produce fewer olefinic and aromatic VOC can be expected to reduce secondary organic PM to a greater extent than other gasoline formulations. The exhibits in Appendix D provide estimates of secondary organic PM impacts using fuel olefin and aromatic content as an *indicator* of exhaust olefin and aromatic content. These estimates should be viewed only in a qualitative sense; indicative of the potential for secondary organic PM reduction. On this basis, either **G3** or **G4** can be expected to reduce secondary organic PM by more than the other formulations. The **G5** formulation should also produce significant secondary organic PM reductions, with the **G1** and **G2** formulations providing lesser benefits.

The **G3** and **G4** formulations produce the greatest toxic emission reductions on both a total mass and potency-weighted mass basis.[7] Both **G1** and **G2** produce minor toxic reductions; **G5** produces toxic reductions about midway between those of the CBG Type 1 and CBG Type 2 formulations.

Wintertime VOC and wintertime NO_x are of lesser importance; both are of primary interest in the context of ozone planning, which is a summertime issue. NO_x emissions do contribute to secondary nitrate PM formation, but such impacts are considered in the PM impacts described above. Nevertheless, the SoW requires an estimate of VOC and NO_x impacts and thus both are presented in Tables 6.3A and 6.3B. The **G3** and **G4** formulations produce the greatest NO_x emission reductions, followed closely by the **G5** formulation. The **G2** formulation produces the greatest VOC emission reductions, followed closely by the **G4** and **G5** formulations.

Appendix D presents gasoline formulation impacts for specific vehicle and engine technologies as well as technology-weighted impacts for each evaluation year. **Appendix E** summarizes the most important of the wintertime emission impacts presented in Tables 6.3A and 6.3B in a series of figures to better illustrate the relative impacts of the gasoline formulations evaluated. Finally, **Appendix F** presents aggregate emissions impacts expressed in terms of percentage reductions in the all-source total, total mobile source, total on-road, and total off-road emissions inventories for Maricopa County.

6.4.2 Diesel Fuel Formulations

Tables 6.4A and 6.4B present the mass emission reductions estimated for each of the diesel fuel formulations.

In considering these impacts, it should be recognized that a number of assumptions were made that could influence the estimated results significantly. While these assumptions are described in more detail in Section 5, they can be summarized briefly as follows.

- The emission reductions model derived by EEA (as detailed in Section 5) would be applicable to both on- and off-road diesel engines.
- Each of the diesel fuel formulations would be used by vehicles that accumulate 85% of the VMT for the diesel on-road fleet and 85% of the off-road diesel activity. The remaining 15% of on-road VMT and off-road activity would accumulate with diesel fuel purchased outside of Maricopa County.

7 Weighting factors were derived from the CARB Predictive Model and are as follows: 0,17 for benzene, 1.0 for 1,3-butadiened, 0.035 for formaldehyde, and 0.016 for acetaldehyde.

This 85% estimate is loosely based on data collected in Denver, and is used for this study in the absence of other credible estimates.

- Secondary particulate formation in the atmosphere for sulfate based particulate would change in proportion to the sulfur content of the fuel.

- Nitrate-based secondary particulate formation would change in proportion to the change in engine-out NO_x emissions.

Emission impacts are provided for PM-10 and PM-2.5 in 2004 and 2010 evaluation years, while those for VOC, CO and NO_x are provided by season for the summers of 1999 and 2010 and the winters of 2004 and 2010.

The largest PM and NO_x reductions are provided by the **D6** formulation, followed by the **G5**, **G4**, **G3**, and **G2** formulations. In general, this same rank order applies to other emission species, except that the **G5** formulation and **G4** formulations provide greater non-PM reductions than the **G6** formulation.

Table 6.3A: Emission Reductions for Gasoline Formulations (metric tons per day)

Pollutant	G1	G2	G3	G4	G5
Calendar Year 2001 (January 1)					
Wintertime CO	2.49	19.74	11.48	32.69	28.47
Calendar Year 2004 (January 1)					
Wintertime VOC	0.90	1.67	0.92	1.51	1.47
Wintertime NO_x	2.93	7.50	10.49	10.57	9.73
Carbonaceous PM-10	0.02	0.03	0.00	0.02	0.02
Sulfate PM-10	0.76	1.72	1.91	1.91	1.83
Nitrate PM-10	0.04	0.10	0.13	0.13	0.12
Total PM-10	0.82	1.84	2.05	2.07	1.98
Carbonaceous PM-2.5	0.02	0.03	0.00	0.02	0.02
Sulfate PM-2.5	0.69	1.55	1.72	1.72	1.65
Nitrate PM-2.5	0.03	0.08	0.11	0.11	0.10
Total PM-2.5	0.73	1.65	1.83	1.84	1.77
Benzene	-0.03	0.14	0.38	0.59	0.24
1,3-Butadiene	0.02	0.04	0.13	0.16	0.11
Formaldehyde	0.02	-0.01	-0.10	-0.10	-0.07
Acetaldehyde	0.04	0.03	0.30	0.03	0.02
Total Toxics	0.05	0.21	0.70	0.67	0.30
Potency-Weighted Toxics	0.02	0.07	0.19	0.26	0.14

Table 6.3B: Emission Reductions for Gasoline Formulations (metric tons per day)

Pollutant	G1	G2	G3	G4	G5
Calendar Year 2010 (January 1)					
Wintertime CO	1.61	16.56	8.82	28.25	24.46
Wintertime VOC	0.91	1.68	0.94	1.52	1.49
Wintertime NO_x	3.10	7.94	11.08	11.17	10.28
Carbonaceous PM-10	0.02	0.04	0.00	0.03	0.03
Sulfate PM-10	0.84	1.88	2.09	2.09	2.01
Nitrate PM-10	0.04	0.10	0.15	0.15	0.14
Total PM-10	0.90	2.03	2.24	2.27	2.17
Carbonaceous PM-2.5	0.02	0.03	0.00	0.02	0.02
Sulfate PM-2.5	0.75	1.70	1.88	1.88	1.81
Nitrate PM-2.5	0.03	0.08	0.12	0.12	0.11
Total PM-2.5	0.81	1.81	2.00	2.02	1.94
Benzene	-0.03	0.14	0.38	0.59	0.24
1,3-Butadiene	0.02	0.04	0.13	0.16	0.11
Formaldehyde	0.02	-0.01	-0.10	-0.10	-0.07
Acetaldehyde	0.04	0.03	0.30	0.03	0.02
Total Toxics	0.06	0.21	0.70	0.67	0.30
Potency-Weighted Toxics	0.02	0.07	0.19	0.26	0.14

Table 6.4A: Emission Reductions for Diesel Fuel Formulations (metric tons per day)

Pollutant	D1	D2	D3	D4	D5	D6
Calendar Year 1999 (July 1)						
Summertime VOC	4.41	4.32	3.63	7.12	9.26	6.78
Summertime NO_x	1.81	2.96	8.45	6.49	10.56	14.65
Summertime CO	14.35	14.43	15.40	25.65	35.16	20.07
Calendar Year 2001 (January 1)						
Wintertime CO	5.16	5.20	5.54	9.23	12.66	7.23
Calendar Year 2004 (January 1)						
Wintertime VOC	2.66	2.61	2.19	4.30	5.59	4.09
Wintertime NO_x	1.05	1.73	4.93	3.79	6.16	8.55
Calendar Year 2010 (January 1)						
Wintertime CO	6.31	6.35	6.77	11.28	15.46	8.83
Wintertime VOC	3.20	3.13	2.63	5.16	6.71	4.91
Wintertime NO_x	1.13	1.85	5.29	4.06	6.60	9.16
Calendar Year 2010 (July 1)						
Summertime VOC	6.27	6.14	5.16	10.11	13.15	9.63
Summertime NO_x	2.20	3.60	10.29	7.90	12.85	17.82
Summertime CO	22.22	22.35	23.84	39.72	54.45	31.09

Table 6.4B: Emission Reductions for Diesel Fuel Formulations (metric tons per year)

Pollutant	D1	D2	D3	D4	D5	D6
Calendar Year 2004						
Carbonaceous PM-10	77	153	423	307	497	1347
Sulfate PM-10	0	232	21	147	246	421
Nitrate PM-10	14	24	68	52	84	117
Total PM-10	92	409	512	507	828	1885
Carbonaceous PM-2.5	73	145	401	291	471	1275
Sulfate PM-2.5	0	208	19	133	222	379
Nitrate PM-2.5	12	19	54	42	68	94
Total PM-2.5	85	373	474	465	760	1748
Calendar Year 2010						
Carbonaceous PM-10	97	192	530	385	623	1688
Sulfate PM-10	0	328	30	209	349	596
Nitrate PM-10	16	26	75	58	94	130
Total PM-10	113	546	635	651	1066	2414
Carbonaceous PM-2.5	93	184	508	369	597	1617
Sulfate PM-2.5	0	295	27	188	314	536
Nitrate PM-2.5	13	21	60	46	75	104
Total PM-2.5	106	500	595	603	986	2258

6.5 Cost-Effectiveness of the Gasoline and Diesel Fuel Options

The key results and findings of the study with respect to estimated costs and changes in vehicle fleet emissions are summarized in **Tables 6.5** (gasoline, Winter season), **6.6 (**diesel fuel, Winter season**)**, and **6.7** (diesel fuel, Summer season).

The tables show the estimated cost-effectiveness measures of the gasoline and diesel formulations considered, by year, in $K per metric ton (mt) of emission reductions.

- Gasoline: **$K /metric ton CO**
- Diesel Fuel: **$K /metric ton (PM (total) + NOx + VOC + 1/7(CO))** and
  $K /metric ton (PM (primary))

The first of the diesel fuel measures was developed by CARB in connection with cost-effectiveness analyses involving multiple pollutants. (This measure does not include secondary nitrate PM generated from NOx emissions.) The second is the customary one for estimating the cost-effectiveness of programs aimed at direct (as opposed to total (direct + indirect)) PM_{10} emissions.

The estimates in Tables 6.5, 6.6, and 6.7 indicate the relative costs and merits of the various fuel formulation options (not as precise assertions of costs or benefits). They offer a means of rank ordering the various fuel formulation, with respect to the technical and economic factors considered in this study.

Following are brief comments on the results shown in Tables 6.5, 6.6, and 6.7.

Gasoline Formulations

- **CBG Type 1 (30 ppm sulfur), CBG Type 2 (3.5 wt.% oxygen)** and **CO Performance Standard gasolines** (**G2, G4,** and **G5**) show the best cost-effectiveness for CO emission reduction. Of the three, **G2** offers the lowest per-gallon cost and daily cost, but provides the least CO emission reduction (about 20 tons/day in 2001 and 17 tons/day in 2010). **G4** has the highest cost, but offers the most CO emission reduction (about 33 tons/day in 2001 and 28 tons/day in 2010. **G5** is intermediate with respect to both cost and CO emission reduction. All three gasolines are low in sulfur and high in oxygen content, the two most important determinants of CO emission reductions in gasoline vehicles.

- **CARB RFG2 (2.0 wt.% oxygen)** (**G3**) shows the worst cost-effectiveness. It has essentially the same sulfur content as the **G2**, **G4**, and **G5** formulations, but lower oxygen content. As a result, it delivers lower CO emission reductions than the other low sulfur gasolines. And, it has the highest refining cost.

- **CBG Type 1 (80 ppm sulfur)** (**G1**) offers low refining and mileage costs and intermediate cost-effectiveness, and it has the lowest aggregate cost to Maricopa County. However, it delivers little CO emission reduction (≈ 0.4%).

- All of the other gasolines deliver small CO emission reductions, ranging from about 2% (**G3)** to about 5% (**G4)**).

- All of the gasolines deliver only small PM_{10} reductions (about 0.5% for **G1** and about 1% for the others).

Diesel Fuel Formulations

- **EPA Diesel (100 ppm sulfur)**, **CARB Diesel (average certified properties)**, and the **Advanced Diesel Blend** (**D2**, **D4,** and **D5**) show the best cost-effectiveness with regard to combined emission reductions of the formulations analyzed. Of the three, **D2** is the most cost-effective, but offers the lowest emission reductions. **D5** has the highest per-gallon and daily cost, but offers the most emission reductions. **D4** is intermediate with respect to both cost and combined emissions reduction.

- **CARB Diesel (formula properties)** and **Swedish Class 1 Diesel** (**D3** and **D6**) show similar and inferior cost-effectiveness with regard to combined emission reductions. **D6** offers the most emission reductions of any of the formulations, but is by far the most expensive; **D3** offers intermediate emission reductions, but at a high cost.

- **EPA Diesel (cetane enhanced) (D1)** has intermediate cost-effectiveness relative to the other formulations. **D1** is the least expensive but offers low emission reductions relative to the other diesel fuel formulations.

- The combined emissions reductions offered by the diesel fuel formulations range from about 0.2% to 2½% of total baseline combined emissions.

Table 6.5: *Gasoline Formulations* -- Cost-Effectiveness; Refining and Mileage Costs; and CO, PM-10, and PM-2.5 Emission Reductions Winter Season

		~ Fed RFG2 with		CARB RFG2		CO
Measure	**Total Baseline Emissions**	**80 ppm Sulfur (G1)**	**30 ppm Sulfur (G2)**	**2.0 wt % Oxygen (G3)**	**3.5 wt % Oxygen (G4)**	**Performance Standard (G5)**
Cost-effectiveness ($K/mt CO)						
2001		18	9	30	9	8
2010		35	13	48	13	11
Refining & Mileage Cost (¢/gal)		**1.3**	**4.8**	**9.7**	**8.3**	**6.2**
Incremental Refining Cost		1.2	4.6	9.9	7.6	5.7
Fuel Economy Cost		0.1	0.2	-0.2	0.7	0.5
Refining Investment Required		Yes	Yes	Yes	Yes	Yes
Maricopa County Cost ($K/day)						
2001		46	171	345	295	220
2010		56	208	420	359	268
Emission Reductions (mt/day)						
CO						
2001	611	2.5	19.7	11.5	32.7	28.5
2010	575	1.6	16.6	8.8	28.3	24.5
PM-10 (total)						
2004	198	0.8	1.8	2.0	2.1	2.0
2010	208	0.9	2.0	2.2	2.3	2.2
PM-2.5 (total)						
2004	110	0.7	1.6	1.8	1.8	1.8
2010	112	0.8	1.8	2.0	2.0	1.9

Note: mt denotes metric tons.

Table 6.6: *Diesel Formulations* -- Cost-Effectiveness; Refining and Mileage Costs; and PM-10, PM-2.5, NOx, VOC, and CO Emission Reductions Winter Season

Measure	Total Baseline Emissions	EPA Diesel with Enhanced Cetane (D1)	EPA Diesel with 100 ppm S + 5 Cet (D2)	CARB Diesel with Formula Properties (D3)	CARB Diesel with Average Properties (D4)	Advanced Diesel Blend (D5)	Swedish Class 1 Diesel (D6)
Cost-effectiveness ($K/mt)							
PM-10 (primary)							
2004		71	46	106	56	60	91
2010		66	41	98	51	55	83
Combination*							
2004		3	4	13	5	6	19
2010		3	4	14	5	6	19
Refining & Mileage Cost (¢/gal)		**1.5**	**2.5**	**12.4**	**5.1**	**8.9**	**35.4**
Incremental Refining Cost		1.5	2.0	10.0	4.0	6.0	32.0
Fuel Economy Cost			0.5	2.4	1.1	2.9	3.4
Refining Investment Required		No	Yes	Yes	Yes	Yes	Yes
Maricopa County Cost ($K/day)							
2004		15	25	125	51	89	356
2010		17	29	144	59	103	412
Emission Reductions (mt/day)							
PM-10 (primary)*							
2004	176	0.2	0.5	1.2	0.9	1.5	3.9
2010	184	0.3	0.7	1.5	1.2	1.9	4.9
PM-10 (total)*							
2004	204	0.3	1.1	1.4	1.4	2.3	5.2
2010	214	0.3	1.5	1.7	1.8	2.9	6.6
PM-2.5 (total)*							
2004	115	0.2	1.0	1.3	1.3	2.1	4.8
2010	117	0.3	1.4	1.6	1.7	2.7	6.2
NOx							
2004	271	1.1	1.7	4.9	3.8	6.2	8.6
2010	283	1.1	1.9	5.3	4.1	6.6	9.2
VOCs							
2004	234	2.7	2.6	2.2	4.3	5.6	4.1
2010	248	3.2	3.1	2.6	5.2	6.7	4.9
CO							
2001	611	5.2	5.2	5.5	9.2	12.7	7.2
2010	575	6.3	6.4	6.8	11.3	15.5	8.8
Combination*							
2004***	805	4.8	6.3	9.4	10.9	16.0	18.9
2010	827	5.5	7.4	10.6	12.6	18.4	21.9

Note: mt denotes metric tons.

* Combined emissions calculated as: PM-10 + NOx + VOCs + CO/7

** Annual average

*** Includes interpolation of CO emissions for 2004.

Table 6.7: *Diesel Formulations* -- Cost-Effectiveness; Refining and Mileage Costs; and PM-10, PM-2.5, NOx, VOC, and CO Emission Reductions Summer Season

		EPA Diesel with		CARB Diesel with		Advanced	Swedish
Measure	**Total Baseline Emissions**	**Enhanced Cetane (D1)**	**100 ppm S + 5 Cet (D2)**	**Formula Properties (D3)**	**Average Properties (D4)**	**Diesel Blend (D5)**	**Class 1 Diesel (D6)**
Cost-effectiveness ($K/mt)							
PM-10 (primary)							
2010		71	45	106	55	59	90
Combination*							
1999		2	*2*	*7*	*3*	*3*	*11*
2010		2	2	8	3	3	12
Refining & Mileage Cost (¢/gal)		**1.5**	**2.5**	**12.4**	**5.1**	**8.9**	**35.4**
Incremental Refining Cost		1.5	2.0	10.0	4.0	6.0	32.0
Fuel Economy Cost			0.5	2.4	1.1	2.9	3.4
Refining Investment Required		No	Yes	Yes	Yes	Yes	Yes
Maricopa County Cost ($K/day)							
1999		14	*23*	*115*	*47*	*83*	*329*
2010		19	31	156	64	112	445
Emission Reductions (mt/day)							
PM-10 (primary)*							
2004	176	0.2	0.5	1.2	0.9	1.5	3.9
2010	184	0.3	0.7	1.5	1.2	1.9	4.9
PM-10 (total)*							
2004	204	0.3	1.1	1.4	1.4	2.3	5.2
2010	214	0.3	1.5	1.7	1.8	2.9	6.6
PM-2.5 (total)*							
2004	115	0.2	1.0	1.3	1.3	2.1	4.8
2010	117	0.3	1.4	1.6	1.7	2.7	6.2
NOx							
1999	332	1.8	3.0	8.5	6.5	10.6	14.7
2010	393	2.2	3.6	10.3	7.9	12.9	17.8
VOCs							
1999	330	4.4	4.3	3.6	7.1	9.3	6.8
2010	299	6.3	6.1	5.2	10.1	13.2	9.6
CO							
1999	1991	14.4	14.4	15.4	25.7	35.2	20.1
2010	2131	22.2	22.4	23.8	39.7	54.5	31.1
Combination*							
1999***	1151	8.5	10.5	15.7	18.7	27.1	29.5
2010	1211	12.0	14.4	20.6	25.5	36.7	38.5

Note: mt denotes metric tons;
italics indicates formulations that could not be implemented by 1999 because of investment requirements.

* Combined emissions calculated as: PM-10 + NOx + VOCs + CO/7

** Annual average

*** Incorporates PM-10 emission reductions estimated for 2004

6.6 Likely Time of Availability of the Gasoline and Diesel Fuel Options

Under business-as-usual conditions (as defined above), the likely first availability – in volumes sufficient to satisfy Maricopa County consumption – of the fuel formulations would be as follows:

- Gasoline: Winter 2001-2002 or Winter 2002-2003
- Diesel fuel: Summer 2000 or Winter 2001-2002

This finding is based on the requirements for capital investment indicated by our analysis, the lead time for making capital investments, and the "trigger date" for undertaking such investments.

- All but one of the gasoline formulations (**G1**) would call for investment in the West refining center, and all would call for investment in the East refining center.

- All but one of the diesel formulations (**D1)** would call for some capital investment in the refining sector (both West and East refining centers).

- All of the diesel formulations would call for some capital investment in the distribution system (other than the CARB diesels (**D3** and **D4**) in the West pipeline system).

In general, refinery investments called for by a new fuel standard are likely to require a lead time of *at least* two years in the East refining center and three or four years in the West refining center, measured from the investment trigger date. Pipeline investments (e.g., additional break-out tanks) are likely to require at least one year. Hence, the pace of refinery investments will determine when the fuel formulations of choice would be available.

Refiners could choose to undertake necessary capital investments as soon as the Arizona legislature puts a new program into state law – say, April 1998 – or as late as full approval of the new Arizona program by all parties (e.g., by EPA) – say, October 1999. These two alternatives define the range of availability dates given above.

Timely completion of the proposed Longhorn pipeline (discussed in Section 6.8) *could* make **G1** (and perhaps **D2**) available to Maricopa County by Winter 2000-2001. The West refining center can produce **G1** for Maricopa County now; the East cannot. If the Longhorn pipeline were in place, Gulf Coast refineries could supply **G1** (and/or **D2**) to Maricopa County in volumes sufficient to make up for any shortfall from the East refining center.

Some of the other fuel formulations – for example, CARB RFG2 or CARB diesel fuel – probably could be supplied sooner than two years after the date of law, if the State of Arizona mandated an early start date. In response to such a mandate, the refining industry *at large* could establish new production and distribution operations to meet Maricopa County demand for the new formulation. Such a situation would involve an increase (possibly an excursion) in the cost of supply, at least for some transition period.

An early start date would mean that at least some refiners now supplying Maricopa County would not have enough lead time to comply with the new program (e.g., by installing new capacity, changing technical operations, adapting business relationships, and establishing compliance procedures) prior to its effective date. The refining sector would go through a transition period before reaching a new steady state, in which the supply pattern might be different than it is now. The likelihood and length of such a transient (with its cost increases) would depend on the effective date of the new program. The sooner it took effect, the more likely, the more severe, and the longer the resulting transient.

6.7 Supply of Diesel Fuel to Areas Outside of Maricopa County

The prospect of new gasoline and diesel fuel formulations for Maricopa County has raised the concern that the new fuels might have adverse effects on the supply and cost of non-taxed (dyed) diesel fuel (high-sulfur or EPA) in rural and mining areas in Arizona.[8] The mining industry in particular now consumes 6K Bbl/day, about 60 % of which is high-sulfur diesel.

Our analysis indicates that the sources of gasoline and diesel fuel supply to Maricopa County are, for the most part, different than the sources of diesel fuel supply to the mining areas. In particular, about 70% of the gasoline and about 90% of the diesel fuel supplied to the Phoenix area comes from the West refining center. Certain refiners in the East refining center do not supply diesel fuel to Maricopa County. All high-sulfur diesel fuel supplied to mining areas comes from certain refineries in the East refining center. EPA diesel fuel supplied to the mining areas comes from the West, East, and Gulf Coast refining centers, in proportions that cannot be established readily.

New gasoline and diesel fuel formulations in Maricopa County are unlikely to have an important effect on the supply of non-taxable diesel fuel available to the mining areas. One or more East refineries might invest in upgrading some of their gasoline and/or diesel fuel output to meet Maricopa County standards. But such investments, if made, would not reduce the overall output of non-taxable EPA and high-sulfur diesel fuel output available for supply to Arizona's mining areas. This finding is based on discussions with East refiners and is consistent with principles of refining economics.

8 EPA diesel is more costly to produce and usually commands a premium of about 2-4¢/gal.

New gasoline and diesel fuel formulations in Maricopa County could increase the cost of supplying non-taxed diesel fuel to the mining areas. The cost of supplying diesel fuel could increase as a consequence of (1) possible investments in the East pipeline system to handle a third grade of diesel fuel, (2) possible investments by bulk terminals in the Phoenix area to handle a third grade of diesel fuel, (3) a possible increase in the proportion of EPA diesel fuel in the non-taxed diesel fuel pool, and (4) an increase in the average cost of production in the refineries that supply Arizona. The combined magnitude of these cost effects is likely to be small on a per-gallon-basis.

The cost effects would be felt by various market segments in Arizona. Forecasting the distribution of possible future costs is beyond the scope of this study.

As noted above, the advent of the Longhorn pipeline could both add to the availability of non-taxable diesel fuel supplies and lower the cost of supplying diesel fuel to Arizona. These possible effects of the Longhorn pipeline would not depend on the new gasoline and diesel fuel formulations of choice in Maricopa County.

6.8 Additional Considerations

6.8.1 Baseline Differentials

The estimated physical properties of the baseline gasoline indicate that gasoline supplied to Maricopa County under the CBG program from 1999 on will have better emission performance than gasoline supplied to Maricopa County prior to the advent of the CBG program – and in particular, the "assumed gasoline" used in the development of baseline emission inventories. A similar situation exists for diesel fuels. The State of Arizona may wish to estimate the magnitude of these increments of emission improvement and their effects on future emission inventories, and to take account of these effects in its planning.

To account for differences in emissions quality between the fuels assumed in estimating Maricopa County baseline inventories and the baseline fuels used in this study, we subtracted (or added, as appropriate) the corresponding emissions differentials *prior to* evaluating individual fuel option benefits. Hence, these emission differentials are not included in the results shown in Exhibits ES-2, ES-3, and ES-4.

6.8.2 Brown Cloud

Consistent with the SoW, we did not assess the effects of the various fuel formulations on the "brown cloud" phenomenon. For reasons of time, resources, and technical feasibility, *quantitative* assessment of effects on the "brown cloud" would not have been feasible. However, *qualitative*, rank-order assessment of the fuel formulations with respect to their likely effects on the brown cloud is possible – through analysis of the PM impacts of the various fuel formulations.
The brown cloud phenomenon is not well understood. There is little doubt that the severity of

the problem depends on the level of light-obscuring PM in the atmosphere. However, brown cloud formation also depends on factors such as meteorology, availability of secondary particulate nucleation sites, and quantity of “natural” light-scattering particles (e.g., water vapor) in the air. These conditions vary over both time and space, making it very difficult to quantify general improvement in the brown cloud phenomenon in relation to any given reduction in PM emissions.

6.8.3 Impacts Outside of Maricopa County

The results of this study indicate little or no impact of the various gasoline and diesel fuel formulations on areas of Arizona outside of Maricopa County.

In particular, our analysis of the refining sector included the premise that after adoption of a new Winter gasoline standard and/or a new diesel fuel standard for Maricopa County, refiners would produce Maricopa County gasoline and/or diesel fuel to the new standard(s) in a manner such that areas in Arizona outside Maricopa County would experience no decrease in the emissions performance of the gasoline and/or diesel fuel that they received.

6.8.4 Through Traffic by Heavy Duty Diesel Vehicles

Through traffic (trips beginning and/or ending outside of Maricopa County) accounts for some (indeterminate) portion of the diesel vehicle miles traveled and the diesel fuel volumes sold and consumed in Maricopa County. The economics and the operating flexibility of the over-the-road trucking industry make it likely that the volume of diesel fuel purchased in Maricopa County would decrease with increasing end-use price (as over-the-road and short-haul truckers elect to purchase EPA diesel outside of Maricopa County). To the extent that this fueling shift occurs, it would affect sellers of diesel fuel in Maricopa County and would reduce the emission benefits of the diesel fuel formulations.

This prospective fueling shift does not lend itself to quantitative analysis, because data on the distribution of diesel vehicle miles traveled (by vehicle category and type of travel) are not available.

In the emissions analysis, we assumed that 15% of the vehicle miles traveled by heavy heavy duty diesel vehicles would be subject to a fueling shift from the Maricopa County diesel fuel formulation to EPA diesel fuel purchased outside Maricopa County. The emissions and cost-effectiveness estimates reflect this fueling shift.

6.8.5 Possible Ban on MTBE Blending in California

The California legislature is considering whether to curtail or terminate the use of MTBE as a gasoline blendstock in California. Without countervailing changes in state and federal regulations, such a move would adversely affect the gasoline-making capability of the California refining sector. It would increase the average cost of CARB RFG produced for in-state consumption and likely would reduce the refineries' overall gasoline out-turn. It could affect the cost, availability, and emission performance of CARB RFG supplied to Maricopa County.

The California Energy Commission is now conducting a study to examine the effects on the supply and price of CARB RFG of a possible ban on MTBE blending. Results of that study should be available by mid-1999. Results of a companion study, on the health effects of MTBE, should be available by the end of 1999.

6.8.6 Possible Effect of Longhorn Pipeline

The advent of the proposed Longhorn Partners Pipeline would be unlikely to change the overall economics, cost-effectiveness, or (with one possible exception, discussed above) the time of availability of the various gasoline and diesel fuel formulations.

The Longhorn pipeline would carry refined products from the U.S. Gulf Coast to El Paso, where it would link to the SFPP East pipeline system. The pipeline could allow Gulf Coast refiners to deliver gasoline and/or diesel fuel to Maricopa County for 2-3☞/gal less than they could now.

The volume of fuel supply from the U.S. Gulf Coast to Maricopa County via the Longhorn pipeline would be limited by the capacity of the SFPP East pipeline system (which now has about 20 M Bbl/day of spare capacity). Without an expansion of the SFPP East pipeline system, the Longhorn pipeline could not deliver enough fuel from the U.S. Gulf Coast to replace the volumes now supplied by the West refining center.

References

1. *Final Report: Assessment of Fuel Quality Options for Maricopa County*, MathPro Inc., November 7, 1996 (submitted to ADEQ)

2. *International Fuel Survey, Gasoline, Summer 1997 and Winter 1997* and *International Fuel Survey, Gasoline, Winter 1996,* American Automobile Manufacturers Association

3. *International Fuel Survey, Diesel Fuel, Summer 1997 and Winter 1997* and *International Fuel Survey, Diesel Fuel, Summer 1996 and Winter 1996,* American Automobile Manufacturers Association

4. *Final Report, 1996 American Petroleum Institute/National Petroleum Refiners Association Survey of Refining Operations and Product Quality,* July 1997

5. *Analysis of Diesel Fuel Quality Issues in Maricopa County, Arizona*, Report No. SR97-12-03, Sierra Research, Inc., 29 December 1997

6. *The California Diesel Fuel Regulations, Title 13, California Code of Regulations, Sections 2281 and 2282*, California Air Resources Board, June 9, 1995

7. *Gas to Liquids (GTL) Conversion – A New Option for Meeting Middle Distillate Demand*, Mark A. Agee, Syntroleum Corporation, March 1, 1997 (presented at the Fifth Annual Middle East Petroleum and Gas Conference)

8. *Diesel Fuel News*, Volume 1, No. 21, Hart Publications, November 19, 1997

9. *Petroleum Refinery Engineering*, Fourth Edition, W. L. Nelson, McGraw Hill, 1958

10. Personal communication with Mr. Dean Simmeroth, California Air Resources Board

11. *Questions Regarding the OTAG Fuel Modeling and Pricing Study*, Memorandum from MathPro Inc. to Mr. R. Rykowski (for OTAG), January 28, 1997 (included in the OTAG docket)

12. *A Review of Primary and Secondary Particulate Matter Associated with Light-Duty Diesel Vehicles: Task 3 Draft Report*, Energy and Environmental Analysis, Inc., August 1997

APPENDIX A:

TASK ASSIGNMENT PROPOSAL
SCOPE OF WORK

Overview: The Arizona Department of Environmental Quality (ADEQ) requires a consultant to provide independent expertise and analysis to the Clean Burning Fuels Subcommittee of the Governor's Air Quality Strategies Task Force. The primary charge of the consultant is to prepare a report, under the direction of the Subcommittee, that will evaluate the following options for modifying gasoline and diesel fuel formulations for the purpose of reducing air pollutant emissions in Maricopa County:

- Gasoline reformulations for the purpose of reducing primarily carbon monoxide (CO) and, secondarily, VOC, NOx and PM emissions in the wintertime; and
- Diesel fuel reformulation options for the purpose of reducing Non-methane Organic Compounds (NMOC), nitrogen oxides (NOx) and particulate matter (PM) emissions.

The report should take into account the unique characteristics of the Maricopa County airshed, refining and delivery system capacity and logistics, cost, (to the extent feasible) cost-effectiveness, and spillover effects (e.g., impacts outside of Maricopa County).

ADEQ and the Subcommittee recognize that this is a quick-response task, and acknowledge that the schedule imposes severe limits on the scope and depth of analysis. Within these limits, the Contractor shall exercise its best efforts to conduct an objective and technically competent analysis.

Tasks:

Task 1: Identification of Fuels Formulations and Regulatory Options:

A. Gasoline Standards

The contractor will investigate the available options for reformulation of gasoline that will reduce emissions of CO during the wintertime. The options shall include:

a) A sulfur content standard;
b) A mandatory California Air Resources Board (CARB) Phase 2 reformulated gasoline program;
c) A CO emissions reduction performance standard; and

d) Other promising regulatory options.

B. Diesel Fuel Reformulation Options

The contractor shall investigate options for changing diesel fuel formulations that will reduce emissions of particulate matter. The options shall include:

a) Adoption of CARB Reformulated Diesel Fuel Standards;
b) More stringent cetane number standards;
c) Limits on aromatic content of diesel fuel;
d) Oxygenated diesel fuel; and
e) Other promising regulatory options.

C. Evaluation of options

The discussion of each of these options shall also include a treatment of:

a) Establishment of baseline fuels, vehicle mix, and other characteristics that will affect the impact of regulatory options being evaluated;
b) Timeliness of implementation with respect to ability to affect CO emissions reductions during the winters of 1999 through 2000, and PM, NMOC and NOx emissions beginning in the year 2000, but no later than 2004;
c) Potential emissions impacts in future years;
d) Regulatory issues that may affect implementation, including state and federal environmental and energy regulations, and the existence of potentially overlapping and conflicting statutes and regulations;
e) Implementation issues, including adequacy of existing regulatory institutions and staffing, necessary statutory and regulatory changes, and the impact and demands on government and regulated industries;
f) Any historical experience with these or similar options, with respect to feasibility, implementation issues, and economic and emissions impacts;
g) To the extent feasible, cost-effectiveness; and
h) Other potential environmental impacts, including effects on other air pollutants, changes in risks related to fuel releases, and effects on waste oil management.

Task 2: Analysis of Impacts on Gasoline and Diesel Fuel Distribution and Effects on Vehicle Performance, Maintenance and Repair

To the extent permitted by the project schedule, the contractor shall explore the feasibility and impacts of each option identified in Task 1 with respect to:

a) Logistics of blending, storage and delivery of gasoline or diesel fuel, as applicable;
b) Distribution system capital improvements and any changes to distribution and storage systems that may be necessary;
c) Added distribution costs per gallon of gasoline or diesel fuel;
d) Administrative and program operations costs to government and other institutions;
e) Time frame for implementation, indicating the earliest date that each of the gasoline or diesel formulations could be implemented, including necessary lead times;
f) Potential supply and distribution impacts outside of Maricopa County in Arizona and outside Arizona;
g) Potential impacts on diesel fuel retail purchasing patterns and consumer purchasing behavior; and
h) Other aspects, including potential impacts on vehicle performance, maintenance and repair.

Task 3: Technical and Economic Analysis of Gasoline and Diesel Fuel Production

To the extent permitted by the project schedule, the contractor shall develop approximate measures or indicators of the incremental per-gallon refining costs associated with the options defined in Task 1 and explore the following technical and economic issues associated with the options:

a) Existing refinery capability and anticipated changes in refineries serving the Maricopa County market, and modifications that may be necessary to meet new standards;
b) Potential fuel economy impacts;
c) Administrative and program costs to government and other institutions;
d) Time frame for implementation, indicating the earliest date that each of the gasoline and diesel formulations could be implemented, including necessary lead times; and
e) To the extent that meaningful and consistent comparisons can be made, and for Maricopa County only, the estimated cost-effectiveness in terms of dollars per ton of PM, NMOC, NOx and CO reduced.

Task 4: Emissions Analysis

The contractor shall assess the emissions impacts of each option identified in Task 1 using existing models and analytical methods, to the extent available, as follows:

a) Estimation of emissions impacts on a per-vehicle basis using an appropriate baseline, within major vehicle technology classifications (e.g. pre-pollution control, catalyst/air injection, closed loop). PM, CO, VOC, NMOC and NOx emissions shall be assessed;

b) Estimation of region-wide emissions impacts with respect to on-road and non-road mobile source inventories for CO in Maricopa County for the years 2000 and 2010, and PM, NMOC, and NOx in the years 2004 and 2010; and

c) Secondary emissions impacts shall be explored, including, hazardous air pollutants (primarily aldehydes, polycyclic organic compounds, benzene and butadiene), a brief literature review regarding possible health impacts of modification of fuel formulations, and effects on emissions outside of Maricopa County.

d) ADEQ shall provide the Contractor all necessary data relating to modeling assumptions, emissions inventories, and other information needed to characterize emissions in Maricopa County.

Task 5: Conclusions

The contractor shall identify all options identified under Task 1 that are technically and logistically feasible and compare them with respect to total costs, cost-effectiveness (to the extent feasible, and in accordance with Task 3, paragraph [e]), and spillover benefits and disbenefits. Conclusions shall also identify caveats with respect to unknowns.

Standards:

The draft and final reports shall:

a) Include a cover page, executive summary, a table of contents, and lists of figures and tables, and technical appendices;

b) Cite sources of information, using end notes for each chapter;

c) Provide detailed descriptions of methods used for analysis in either the text or a technical appendix, including identification of all models and analytical techniques, explicit and implicit assumptions, and reliability/precision/accuracy of the method. Where non-proprietary models are used, program code or spreadsheet formulae shall be provided in printed form as part of a technical appendix; and

d) Contractor shall provide two copies of the Final Report, 1 unbound master, and an electronic copy of the report in WordPerfect 6.1 for Windows format on 3.5" floppy diskettes. In addition, contractor shall provide on 3.5" floppy diskettes, copies of all spreadsheets and nonproprietary models used for the analyses conducted to produce the report.

SPECIAL INSTRUCTIONS

1. Confidentiality: Contractor shall take all precautions necessary and exercise due diligence to protect and not divulge information that is declared by a source as constituting either a trade secret or information likely to cause substantial harm to the competitive position of its client or company (See ARS §§ 49-201(31) and 49-432(C)(1), attached). Contractor shall not accept information considered by its source to be confidential unless it is clearly identified as such either on transmittal correspondence or on the documents themselves. An example of an adequate declaration appears below. All such information shall be maintained in a secured file, and shall be hand delivered to ADEQ in a sealed package clearly marked as being confidential.

   Example confidential information declaration:

   "Pursuant to ARS §49-432(C)(1), I declare this information as constituting either a trade secret or information that, if disclosed, is likely to cause substantial harm to the competitive position of this company.

   ____"

   Signature

2. Business and Financial Interest: Provide a certification regarding current status with respect to existing contracts with or outstanding obligations to clients, or legal, financial or corporate relationship to persons directly involved in the business of refining, supplying or distributing fungible gasoline or diesel fuel or refined stocks that my be blended to create fungible gasoline or diesel fuel, or products that may be used as additives to gasoline or diesel fuel, destined for use in Arizona. Such statement may name clients, but must state whether or not a contractual or legal relationship exists between such persons. Such statement shall describe any and all corporate and financial relationships between offeror and such persons. This information shall be evaluated as it pertains to the real and perceived independence and credibility of the result as it relates to this project.

3. Please submit Pricing Schedule that specifies Key Personnel, amount of hours needed to complete each Task, price per hour, and total cost for the Task Assignment. Please add travel expenses as a separate line. Prices shall be all inclusive with the exception of travel expenses as specified in contract.

SCHEDULE OF DELIVERABLES

	DELIVERABLE	DATE
1.	Meeting with the Subcommittee for discussion of issues related to the scope of work, presentation on method of approach and data needs; preliminary list of options.	December 8, 1997
2.	Draft Final Report.	January 30, 1998

Contractor shall provide the Subcommittee 20 copies of all written materials with each progress report, and shall deliver an oral presentation that includes a review of all aforementioned written materials.

APPENDIX B: DETAILED RESULTS OF THE REFINING ANALYSIS OF GASOLINE FORMULATIONS

Exhibit B-1.1: East Notional Refinery: Estimated Cost of Gasoline Formulations, by Case

Measure	~Fed RFG 2 with 80 ppm Sulfur (G1)	~Fed RFG 2 with 30 ppm Sulfur (G2)	CARB RFG2 2.0 wt % Oxygen (G3)	CARB RFG2 3.5 wt % Oxygen (G4)	CO Performance Standard (G5)
Total Average Cost (¢/gal.)*	**3.7**	**7.2**	**15.2**	**13.3**	**9.3**
Variable Refining Cost	1.4	0.7	9.9	8.2	2.0
Capital Charge	2.3	6.5	5.3	4.4	6.6
Mileage Loss	0.1	0.0	0.1	0.7	0.6
Investment ($ million)	10	23	25	20	22

Exhibit B-1.2: East Notional Refinery: Modeling Results -- Crude Oil Inputs, Process Unit Utilization, Additions, and Operations, by Case

Refining Processes	1999 Baseline		~Fed RFG 2 with		CARB RFG2		CO
	Summer	Winter	80 ppm Sulfur (G1)	30 ppm Sulfur (G2)	2.0 wt % Oxygen (G3)	3.5 wt % Oxygen (G4)	Performance Standard (G5)
Crude Oil Input	56.5	56.1	55.7	55.4	56.5	56.5	55.2
Existing Capacity (K Bbl/day)							
Fluid Cat Cracker	17.8	17.5	16.6	16.8	15.6	15.6	16.7
Coking - Delayed	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Alkylation	4.9	4.0	4.5	4.5	4.2	4.2	4.5
Reforming - Low pressure	7.5	7.3	7.2	7.2	7.0	5.8	7.1
Reforming - High pressure	2.0	2.0	2.0	2.0	2.0	3.1	2.0
Deep Distillate Desulfurization	0.7	1.0	1.0	1.0	1.0	1.0	1.0
Distillate Desulfurization	15.7	15.7	15.7	15.7	15.7	15.7	15.7
FCC Gasoline Desulfurization	0.0	0.8	0.8	0.8	0.8	0.8	0.8
Reformer Feed Desulfurization	9.2	8.6	8.8	8.6	8.7	8.9	8.2
FCC Gasoline Splitter #1		1.1	1.5	1.5	1.5	1.5	1.5
C4 Isomerization	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Debutanization	2.0	1.5	1.4	1.5	1.3	1.3	1.4
Hydrogen Plant (foeb)							
New Capacity (K Bbl/day)							
Deep Distillate Desulfurization	0.4	0.1					0.0
Distallate Desulfurization			0.5	0.6	0.1	0.1	0.8
FCC Gasoline Desulfurization	0.8		0.1	1.0	0.5	0.4	1.0
FCC Gasoline Splitter #1	1.6		0.7	0.9	0.2	0.1	1.2
Benzene Removal			0.0	0.0	0.1	0.1	
Operating Indices							
FCC Conversion (Vol %)	72.9	71.9	70.8	70.5	70.9	71.0	70.1
Reformer Severity (RON)	97.5	98.1	96.7	97.7	95.8	94.8	98.4
Charge Rates (K Bbl/day)							
Fluid Cat Cracker	18.6	18.4	17.9	18.2	16.7	16.7	18.1
Reformer (150-350 psi)	9.2	8.6	8.8	8.6	8.7	8.8	8.1

Exhibit B-1.3: East Notional Refinery: Modeling Results – Gasoline Properties & Composition, by Case

Property, Composition, & Volume	1999 Baseline				~ Fed RFG 2 with			
	Summer		Winter		80 ppm Sulfur (G1)		30 ppm Sulfur (G2)	
	Conv	Maricopa	Conv	Maricopa	Conv	Maricopa	Conv	Maricopa
Property								
RVP (psi)	8.7	6.7	12.0	7.7	12.0	7.7	12.0	7.7
Oxygen (wt%)	0.0	2.1	0.0	3.5	0.0	3.5	0.0	3.5
Aromatics (vol%)	32.3	25.0	29.4	27.5	28.2	27.5	28.2	27.5
Benzene (vol%)	2.4	1.8	2.4	1.3	2.2	1.5	2.2	1.5
Olefins (vol%)	12.0	8.0	12.0	9.3	12.0	9.3	12.0	6.0
Sulfur (ppm)	350	170	350	200	350	80	350	30
E200 (vol% off)	45.9	49.5	50.0	53.5	50.0	52.8	50.0	52.9
E300 (vol% off)	84.2	86.8	86.0	84.9	86.1	88.9	85.9	86.3
T50*	210	201	194	186	195	187	195	186
T90*	314	310	310	319	310	303	311	311
En. Den. (MM Btu/bbl)	5.226	5.079	5.166	5.035	5.159	5.031	5.160	5.033
Composition (vol%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	6.4	3.0	11.4	5.3	11.4	5.1	11.4	4.9
Butenes			0.2					
I-Butane	4.6		6.4	0.8	7.6		7.8	
N-Butane	1.8	3.0	4.8	4.5	3.7	5.1	3.6	4.9
C5s & Isomerate								
Raffinate					0.0	0.1		0.1
Natural Gas Liquids								
Naphtha	10.7	9.9	10.9	15.8	12.6	8.1	13.5	7.4
C5-160	10.7	9.9	10.9	9.1	11.2	8.1	11.5	7.4
Coker Naphtha								
160-250				6.7	1.3		2.0	
Alkylate	14.6	21.8	14.2	12.5	15.4	15.6	15.2	16.4
Hydrocrackate								
FCC Gasoline:	40.6	27.9	39.1	29.7	38.1	26.9	37.8	28.6
Full Range	38.9	18.3	39.1	20.1	38.1	6.3	37.7	6.9
Light								
Medium	1.7					9.9	0.1	0.8
Medum - Desulf.		4.7		6.2		3.5		13.1
Heavy								
Heavy - Desulf.		4.9		3.5		7.2		7.9
Reformate	27.7	25.9	24.3	26.6	22.5	34.1	22.1	32.5
Light	16.1	12.5	18.1	1.5	16.3	7.7	15.3	7.8
Heavy	11.6	13.4	6.2	25.1	6.3	26.4	6.8	24.7
MTBE		11.5			0.1		0.0	
Ethanol				10.1		10.1		10.1
Gasoline Volume (K Bbl/day)	20.0	8.0	20.0	8.0	20.0	8.0	20.0	8.0

* Interpolated using ARMS generated distillation curves.

Exhibit B-1.3: East Notional Refinery: Modeling Results – Gasoline Properties & Composition, by Case

Property, Composition, & Volume	CARB RFG2 2.0 wt % Oxygen (G3)		CARB RFG2 '3.5 wt % Oxygen (G4)		CO Performance Standard (G5)	
	Conv	Maricopa	Conv	Maricopa	Conv	Maricopa
Property						
RVP (psi)	12.0	8.7	12.0	7.7	12.0	7.7
Oxygen (wt%)	0.6	2.2	0.7	3.5	0.2	3.5
Aromatics (vol%)	28.2	23.0	28.2	23.0	28.2	24.0
Benzene (vol%)	2.2	0.6	2.2	0.6	2.2	1.5
Olefins (vol%)	12.0	3.9	12.0	3.9	12.0	6.2
Sulfur (ppm)	350	20	350	20	350	25
E200 (vol% off)	51.5	51.0	52.6	52.9	50.0	56.4
E300 (vol% off)	85.2	88.8	86.6	88.8	85.1	89.9
T50*	190	193	187	189	195	181
T90*	313	304	309	304	314	300
En. Den. (MM Btu/bbl)	5.130	5.032	5.115	5.000	5.154	4.999
Composition (vol%)	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	11.2	6.2	11.1	4.8	11.6	4.2
Butenes						
I-Butane	8.3		8.2		7.9	
N-Butane	3.0	6.2	2.9	4.8	3.7	4.2
C5s & Isomerate						
Raffinate		1.0		0.8		
Natural Gas Liquids						
Naphtha	13.8	8.4	13.4	8.0	15.2	8.9
C5-160	11.3	8.4	11.5	8.0	10.8	8.9
Coker Naphtha						
160-250	2.5		1.9		4.4	
Alkylate	10.5	24.4	9.2	27.9	12.7	22.1
Hydrocrackate						
FCC Gasoline:	39.7	14.1	39.8	13.9	38.9	24.0
Full Range	37.5	4.5	37.7	4.6	36.1	7.6
Light						
Medium					0.7	
Medum - Desulf.		9.6		9.3		13.7
Heavy						
Heavy - Desulf.	2.2		2.1		2.0	2.7
Reformate	21.7	33.7	22.4	34.5	20.5	30.8
Light	15.1	7.7	18.4	1.4	13.4	7.7
Heavy	6.6	26.0	4.0	33.0	7.1	23.1
MTBE	3.1	12.1	4.1		1.1	
Ethanol				10.1		10.1
Gasoline Volume (K Bbl/day)	20.0	8.0	20.0	8.0	20.0	8.0

* Interpolated using ARMS generated distillation curves.

Exhibit B-1.4: East Notional Refinery: Modeling Results -- Crude Oil, Other Inputs, and Refined Product Outputs, by Case

(K barrels/day)

Refining Processes	1999 Baseline		~Fed RFG 2 with		CARB RFG2		CO
	Summer	Winter	80 ppm Sulfur (G1)	30 ppm Sulfur (G2)	2.0 wt % Oxygen (G3)	3.5 wt % Oxygen (G4)	Performance Standard (G5)
Crude Oil							
Domestic Composite	56.5	56.1	55.7	55.4	56.5	56.5	55.2
Other Inputs							
Isobutane	0.9	0.8	1.4	1.4	1.4	1.4	1.4
Butane	0.4	1.2	1.0	1.0	1.0	0.9	0.9
MTBE	0.9	0.0	0.0	0.0	1.6	0.8	0.2
Ethanol	0.0	0.8	0.8	0.8	0.0	0.8	0.8
Purchased Energy							
Electricity (K Kwh)	195	187	190	192	189	189	190
Fuel (foeb)	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Refined Products							
Coker Naphtha	0.1	0.1	0.1	0.1	0.1	0.1	0.1
BTX	0.0	0.0	0.0	0.0	0.1	0.1	0.0
Propane	1.5	1.5	1.5	1.5	1.4	1.4	1.5
Butane							
Gasoline:							
Conventional	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Maricopa County	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Jet Fuel	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Diesel Fuel (< 0.05% Sulf)	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Heating Oil	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Resid - Low Sulfur	1.0	1.3	1.0	1.0	1.4	1.4	1.0
Resid - High Sulfur	2.9	2.9	3.2	2.8	4.2	4.2	2.8
Asphalt	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Coke	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sulfur (K tons/d)	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Exhibit B-2.1: West Notional Refinery: Estimated Cost of Gasoline Formulations, by Case

Measure	~Fed RFG 2 with 80 ppm Sulfur (G1)	~Fed RFG 2 with 30 ppm Sulfur (G2)	CARB RFG2 2.0 wt % Oxygen (G3)	CARB RFG2 3.5 wt % Oxygen (G4)	CO Performance Standard (G5)
Total Average Cost (¢/gal.)*	**0.5**	**3.9**	**7.6**	**6.4**	**5.1**
Variable Refining Cost	0.3	2.8	6.2	3.8	3.3
Capital Charge	0.0	0.9	1.7	1.9	1.4
Mileage Loss	0.2	0.3	-0.3	0.8	0.5
Investment ($ million)	0	14	30	32	24

Exhibit B-2.2: West Notional Refinery: Modeling Results – Crude Oil Inputs, Process Unit Utilization, Additions, and Operations, by Case

Refining Processes	1999 Baseline Summer	1999 Baseline Winter	~Fed RFG 2 with 80 ppm Sulfur (G1)	~Fed RFG 2 with 30 ppm Sulfur (G2)	CARB RFG2 2.0 wt % Oxygen (G3)	CARB RFG2 3.5 wt % Oxygen (G4)	CO Performance Standard (G5)
Crude Oil Input	148.7	146.1	146.1	146.3	146.1	146.2	146.5
Existing Capacity (K Bbl/day)							
Fluid Cat Cracker	40.7	38.2	38.1	38.2	37.5	37.8	37.6
Hydrocracker - Distillate Feed	14.2	14.2	14.2	14.2	14.2	14.2	14.2
Hydrocracker - Gas Oil Feed	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Coking - Delayed	42.2	42.9	43.1	43.8	44.3	44.1	44.6
Alkylation	12.9	11.6	11.6	11.5	11.9	12.0	11.7
C5/C6 Isomerization (tot. recycle)	2.6	1.3	1.3	2.6	2.6	2.6	2.6
Reforming (150-350 psi)	25.1	25.4	25.3	23.5	23.7	23.5	23.5
MTBE Plant	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Deep Distillate Desulfurization	13.8	13.9	13.9	13.9	13.9	13.9	13.9
Distillate Desulfurization	28.3	28.3	28.1	28.3	28.3	28.3	28.3
FCC Feed Desulfurization	35.8	34.5	34.4	33.3	33.0	33.0	32.8
FCC Gasoline Desulfurization	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Naphtha & Isom Feed Desulf.	5.3	4.1	4.1	7.7	7.4	7.1	7.7
Reformer Feed Desulfurization	20.1	18.1	18.1	18.7	18.9	18.9	19.0
FCC Gasoline Splitter #1	20.6	20.8	21.4	22.5	21.8	22.1	21.9
FCC Gasoline Splitter #2 (C5s)	0.6	0.0	0.0	0.0	0.8	0.9	0.3
Benzene Removal	4.4	6.4	6.5	6.9	6.9	6.9	6.9
C4 Isomerization	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Debutanization	11.0	9.7	9.8	9.5	9.6	9.3	9.6
Hydrogen Plant (foeb)	3.9	4.0	4.0	4.0	4.0	4.0	4.0
New Capacity (K Bbl/day)							
FCC Gasoline Splitter #1	2.6						
FCC Gasoline Splitter #2	0.4						
FCC Gasoline Splitter #3				1.4			0.4
Deep Distillate Desulfurization	0.1						
FCC Gasoline Desulfurization				0.3	1.2	1.3	0.9
Benzene Removal	3.0						
Hydrogen Plant (foeb)	0.1						
Operating Indices							
FCC Conversion (Vol %)	76.6	76.4	76.6	76.2	75.7	75.5	76.1
Reformer Severity (RON)	93.4	95.2	95.1	93.9	93.9	93.5	94.4
Charge Rates (K Bbl/day)							
Fluid Cat Cracker	40.5	38.1	37.9	37.9	37.3	37.5	37.4
Reformer (150-350 psi)	26.5	24.7	24.8	24.5	25.1	25.1	24.4

Exhibit B-2.3: West Notional Refinery: Modeling Results – Gasoline Properties & Composition, by Case

Property, Composition, & Volume	1999 Baseline						~ Fed RFG 2 with					
	Summer			Winter			80 ppm Sulfur (G1)			30 ppm Sulfur (G2)		
	Cal RFG	Maricopa	Conv	Cal RFG	Maricopa	Conv	Cal RFG	Maricopa	Conv	Cal RFG	Maricopa	Conv
Property												
RVP (psi)	6.8	6.6	8.7	11.2	7.7	11.2	11.2	7.7	11.2	11.2	7.7	11.2
Oxygen (wt%)	1.8	2.1	0.2	1.8	3.5	0.0	1.8	3.5	0.0	1.8	3.5	0.2
Aromatics (vol%)	23.0	28.6	37.0	23.0	28.0	28.6	23.0	27.7	29.0	23.0	25.0	23.8
Benzene (vol%)	0.55	0.75	0.75	0.55	0.75	0.75	0.55	0.75	0.75	0.55	0.75	0.75
Olefins (vol%)	3.9	10.5	10.5	3.9	10.5	10.5	3.9	10.5	10.5	3.9	10.5	10.5
Sulfur (ppm)	20	90	90	20	90	90	20	80	90	20	30	90
E200 (vol% off)	51.5	49.2	35.4	55.8	51.0	50.0	55.8	51.0	50.0	56.2	52.4	49.0
E300 (vol% off)	89.7	84.0	80.4	90.0	86.0	85.3	90.0	88.6	84.0	90.0	89.0	89.8
T50*	197	202	232	188	197	200	187	198	200	187	194	201
T90*	302	337	347	300	320	326	300	308	335	300	304	302
En. Den. (MM Btu/bbl)	5.087	5.123	5.262	5.034	5.055	5.175	5.037	5.045	5.158	5.034	5.039	5.110
Composition (vol%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	2.2	2.5	8.9	9.6	5.4	9.5	9.7	5.6	9.2	9.6	4.8	9.9
Butenes												
I-Butane						1.3			1.2			3.4
N-Butane	2.2	2.5	8.9	9.6	5.4	8.3	9.7	5.6	8.0	9.6	4.8	6.5
C5s & Isomerate	3.5			1.8					14.2	1.7		15.1
Raffinate												
Natural Gas Liquids												
Naphtha	7.0	9.0	2.1	8.1	13.1	12.7	10.0	7.8	1.9	7.8	8.9	0.0
C5-160	5.5	9.0	2.0	6.0	7.9	12.5	7.7	4.8	1.9	6.8		
Coker Naphtha												
160-250	1.5		0.0	2.0	5.1	0.2	2.3	3.0		0.9	8.9	
Alkylate	19.5	0.9	1.5	14.3	2.7	5.2	14.9	3.7	0.0	12.7	16.6	4.2
Hydrocrackate	12.2	6.8	10.0	12.2	4.4	10.2	11.9	6.0	11.3	13.8		11.7
FCC Gasoline:	16.8	59.9	65.3	17.6	61.3	45.6	16.3	62.8	53.2	19.6	28.6	57.2
Full Range		11.4			6.2	13.6	0.1		11.7			
Light	5.5	6.7	3.3	5.4	5.0	5.3	5.7	5.8	3.5	5.2	15.7	0.1
Medium	4.2	22.7	38.5	3.7	26.3	20.2	3.1	31.5	24.7	4.0	8.3	42.8
Medum - Desulf.	3.9			4.7			4.1	3.0		4.8	0.6	
Heavy												
Heavy - Desulf.	3.1	19.2	23.5	3.9	23.8	6.5	3.4	22.6	13.3	5.6	4.0	14.3
Reformate	28.8	9.3	11.2	26.5	3.1	16.8	27.4	4.1	10.3	25.1	31.1	0.9
Light	9.0	5.5		8.9		1.1	8.6	4.1		9.7		
Heavy	19.8	3.8	11.2	17.6	3.1	15.7	18.8		10.3	15.3	31.1	0.9
MTBE	9.9	11.5	1.1	9.9			9.9			9.9		1.1
Ethanol					10.1			10.1			10.1	
Gasoline Volume (K Bbl/day)	72.0	9.0	9.0	72.0	9.0	9.0	72.0	9.0	9.0	72.0	9.0	9.0

* Interpolated using ARMS generated distillation curves.

Exhibit B-2.3: West Notional Refinery: Modeling Results – Gasoline Properties & Composition, by Case

Property, Composition, & Volume	CARB RFG2						CO Performance Standard (G5)		
	2.0 wt % Oxygen (G3)			'3.5 wt % Oxygen (G4)					
	Cal RFG	Maricopa	Conv	Cal RFG	Maricopa	Conv	Cal RFG	Maricopa	Conv
Property									
RVP (psi)	11.2	8.7	11.2	11.2	7.7	11.2	11.2	7.7	11.2
Oxygen (wt%)	1.8	1.8	0.0	1.8	3.5	0.0	1.8	3.5	0.0
Aromatics (vol%)	23.0	23.0	28.1	23.0	23.0	27.4	23.0	24.0	25.7
Benzene (vol%)	0.55	0.55	0.75	0.55	0.55	0.75	0.55	0.75	0.75
Olefins (vol%)	3.9	3.9	10.5	3.9	3.9	10.5	3.9	6.0	10.5
Sulfur (ppm)	20	20	90	20	20	90	20	25	90
E200 (vol% off)	54.9	54.0	49.0	55.1	55.0	50.0	56.2	51.5	49.0
E300 (vol% off)	88.8	88.8	88.8	89.0	89.0	90.0	90.0	87.0	88.6
T50*	189	192	201	189	191	200	187	196	201
T90*	306	308	312	306	304	300	300	314	312
En. Den. (MM Btu/bbl)	5.039	5.071	5.160	5.038	5.012	5.154	5.036	5.027	5.136
Composition (vol%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C4s:	9.9	5.0	10.2	9.8	3.9	9.7	9.7	4.6	9.9
Butenes									
I-Butane			1.5			4.4			1.6
N-Butane	9.9	5.0	8.7	9.8	3.9	5.3	9.7	4.6	8.3
C5s & Isomerate	1.4	1.4	15.6	1.0	6.2	14.1	1.4		17.1
Raffinate									
Natural Gas Liquids									
Naphtha	6.0	19.4	3.0	6.5	12.6	6.4	7.6	10.0	0.7
C5-160	4.9	13.1	3.0	5.5	4.5	6.4	6.8	0.2	0.7
Coker Naphtha									
160-250	1.1	6.3		1.0	8.1		0.8	9.8	
Alkylate	13.0	22.1	0.0	12.9	23.7	0.0	11.4	30.3	2.4
Hydrocrackate	13.6	4.7	3.9	13.7	4.5	2.8	14.7		8.1
FCC Gasoline:	19.9	17.8	59.8	20.3	16.2	59.1	19.0	31.6	56.1
Full Range			2.3			1.1			2.7
Light	5.1	6.5	4.8	5.2	5.4	5.3	5.0	12.5	2.2
Medium	4.3		37.7	4.0	2.2	38.9	4.5		39.0
Medum - Desulf.	5.8			5.8			5.5		
Heavy									
Heavy - Desulf.	4.7	11.3	15.0	5.3	8.5	13.7	4.0	19.1	12.2
Reformate	26.3	19.8	7.5	25.9	22.8	7.9	26.4	13.5	5.7
Light	7.9	7.4	7.1	8.7		7.9	9.7		
Heavy	18.4	12.4	0.4	17.2	22.8		16.7	13.5	5.7
MTBE	9.9	9.9		9.9			9.9		
Ethanol					10.1			10.1	
Gasoline Volume (K Bbl/day)	72.0	9.0	9.0	72.0	9.0	9.0	72.0	9.0	9.0

* Interpolated using ARMS generated distillation curves.

Exhibit B-2.4: West Notional Refinery: Modeling Results – Crude Oil, Other Inputs, and Refined Product Outputs, by Case
(K barrels/day)

Refining Processes	1999 Baseline		~Fed RFG 2 with		CARB RFG2		CO Performance Standard (G5)
	Summer	Winter	80 ppm Sulfur (G1)	30 ppm Sulfur (G2)	2.0 wt % Oxygen (G3)	3.5 wt % Oxygen (G4)	
Crude Oil							
Domestic Composite	66.0	66.0	66.0	66.0	66.0	66.0	66.0
Foreign Composite	13.0	13.0	13.0	13.0	13.0	13.0	13.0
Alaskan North Slope	69.7	67.1	67.1	67.3	67.1	67.2	67.5
Other Inputs							
Isobutane	0.5	0.0	0.0	0.2	0.3	0.6	0.1
Butane	0.8	5.3	5.3	5.1	5.5	5.1	5.3
Natural Gas Liquids	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Alkylate	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Naphtha	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Heavy Gas Oil	3.0	3.0	3.0	3.0	3.0	3.0	3.0
MTBE	7.5	6.3	6.3	6.4	7.2	6.3	6.3
Ethanol	0.0	0.9	0.9	0.9	0.0	0.9	0.9
Methanol	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Purchased Energy							
Electricity (K Kwh)	1173	1143	1144	1156	1159	1158	1157
Fuel (foeb)	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Refined Products							
Heavy Reformate							
Propane	4.5	3.4	3.4	3.4	3.4	3.3	3.4
Butane							
Gasoline:							
California RFG	72.0	72.0	72.0	72.0	72.0	72.0	72.0
Maricopa County	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Conventional	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Jet Fuel	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Diesel Fuel (< 0.05% Sulf)	23.0	23.0	23.0	23.0	23.0	23.0	23.0
Heating Oil	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Resid - Low Sulfur	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Resid - High Sulfur	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Asphalt	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Coke	9.1	9.1	9.1	9.4	9.4	9.4	9.5
Sulfur (K tons/d)	0.4	0.4	0.4	0.3	0.3	0.3	0.3

APPENDIX C: EPA COMPLEX MODEL CO RELATIONS

This appendix presents a series of graphics illustrating the gasoline parameter relations that make up the CO version of the EPA's reformulated gasoline Complex Model. Graphics are included for all Complex Model inputs, regardless of CO model sensitivity. For example, a graphic for benzene is included although the CO model is completely insensitive to fuel benzene content (except in terms of benzene content impacts on total fuel aromatics). With the exception of benzene content, the CO model is sensitive to some degree to all Complex Model fuel parameters. The parameters to which the model shows the most sensitivity are: (1) fuel sulfur content, (2) fuel oxygen content, and (3) fuel aromatic content. Fuel distillation characteristics also show a significant influence over certain distillation ranges.

Each graphic presented in this appendix includes a dashed line indicating the baseline Maricopa County gasoline quality. This allows for a visual determination of potential *local* CO impacts associated with any given alternative gasoline formulation.

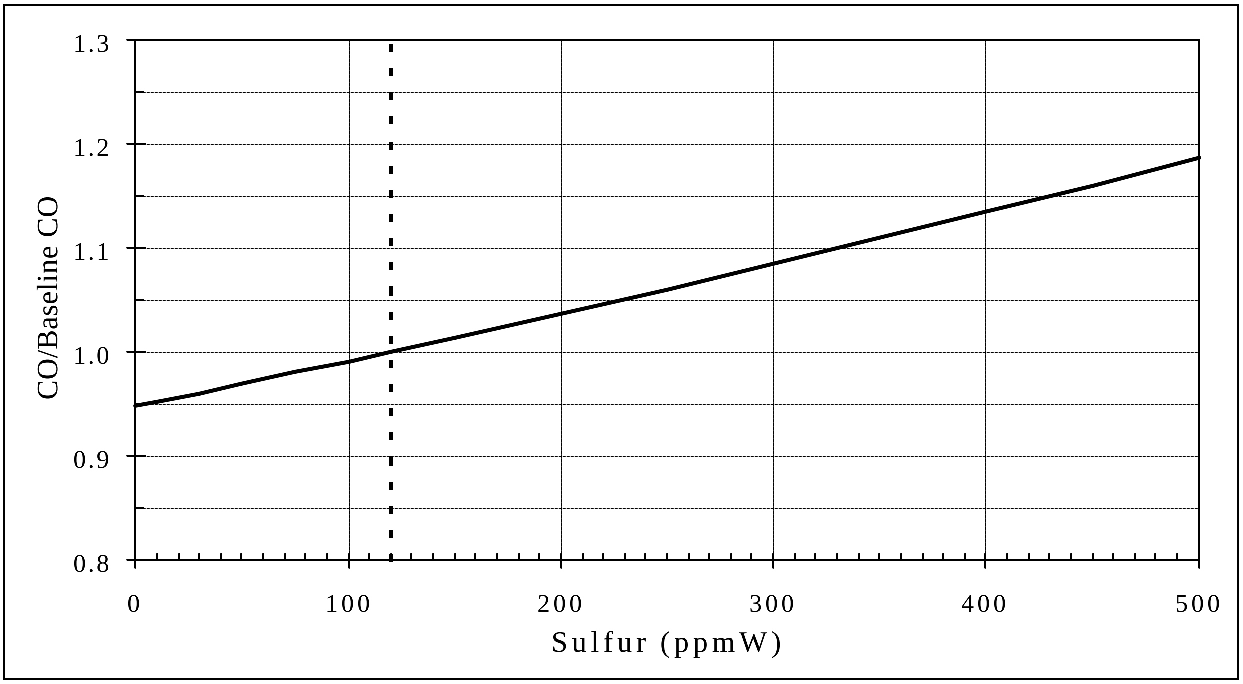

Exhibit C.1: CO Complex Model Sulfur Content Relationship

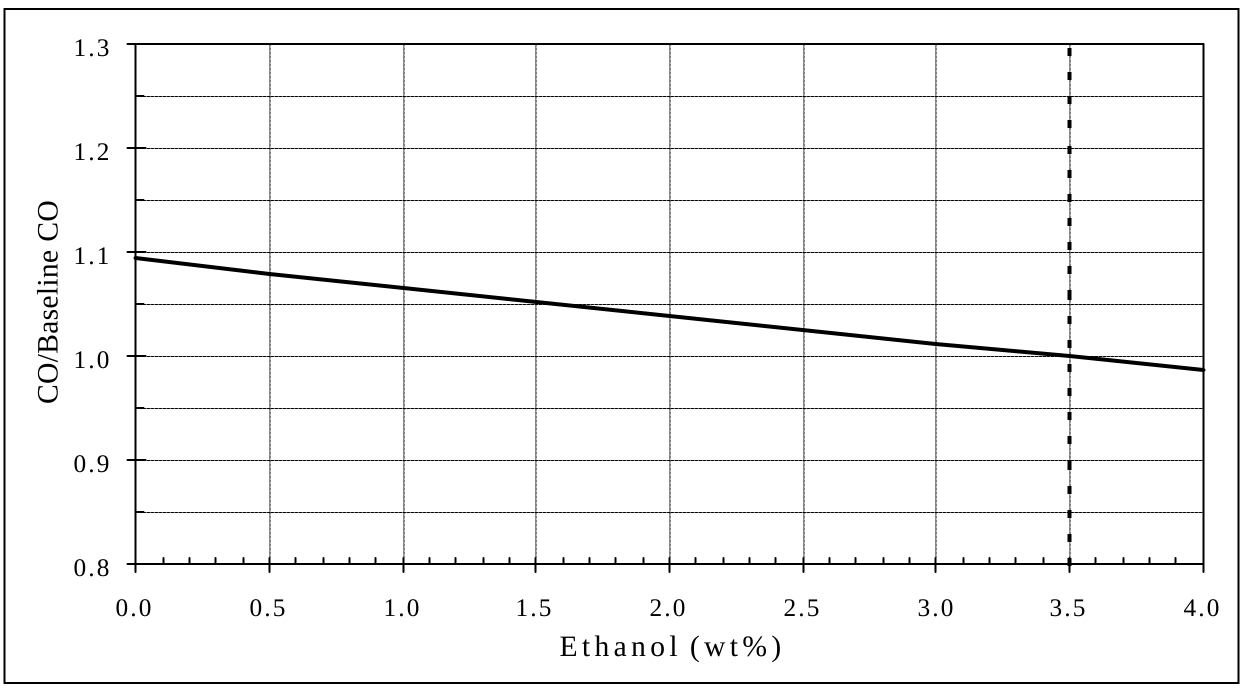

Exhibit C.2: CO Complex Model Ethanol Content Relationship

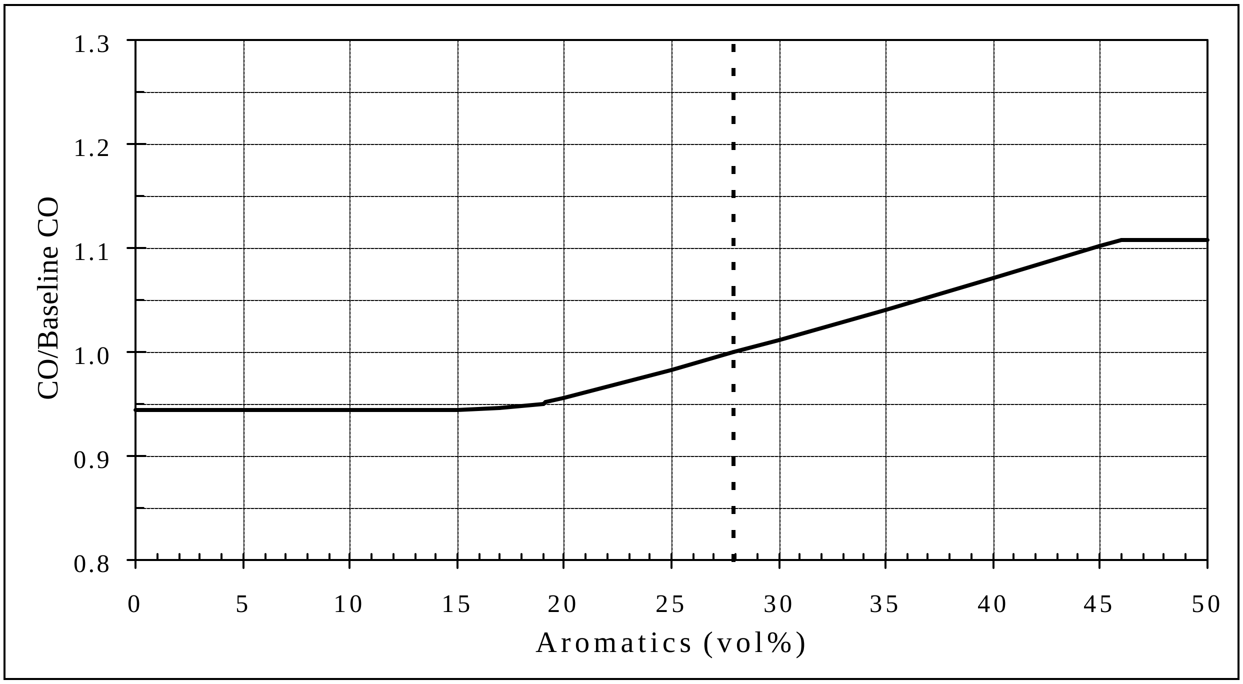

Exhibit C.3: CO Complex Model Aromatic Content Relationship

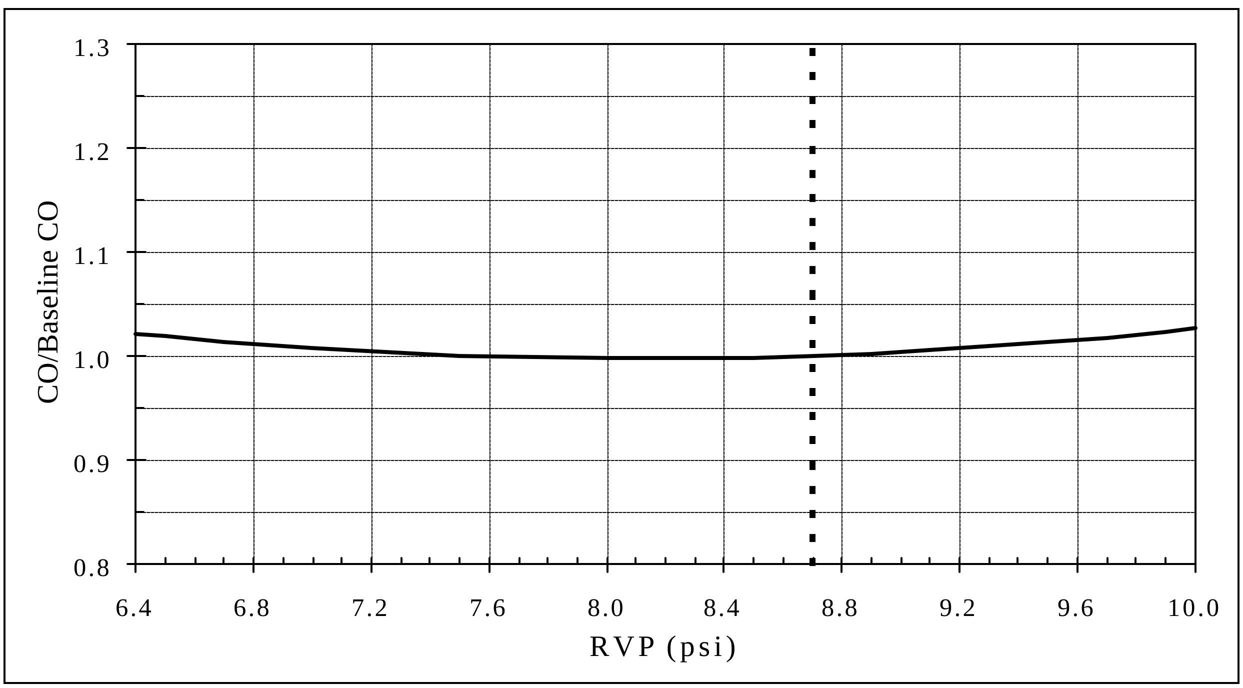

Exhibit C.4: CO Complex Model RVP Relationship

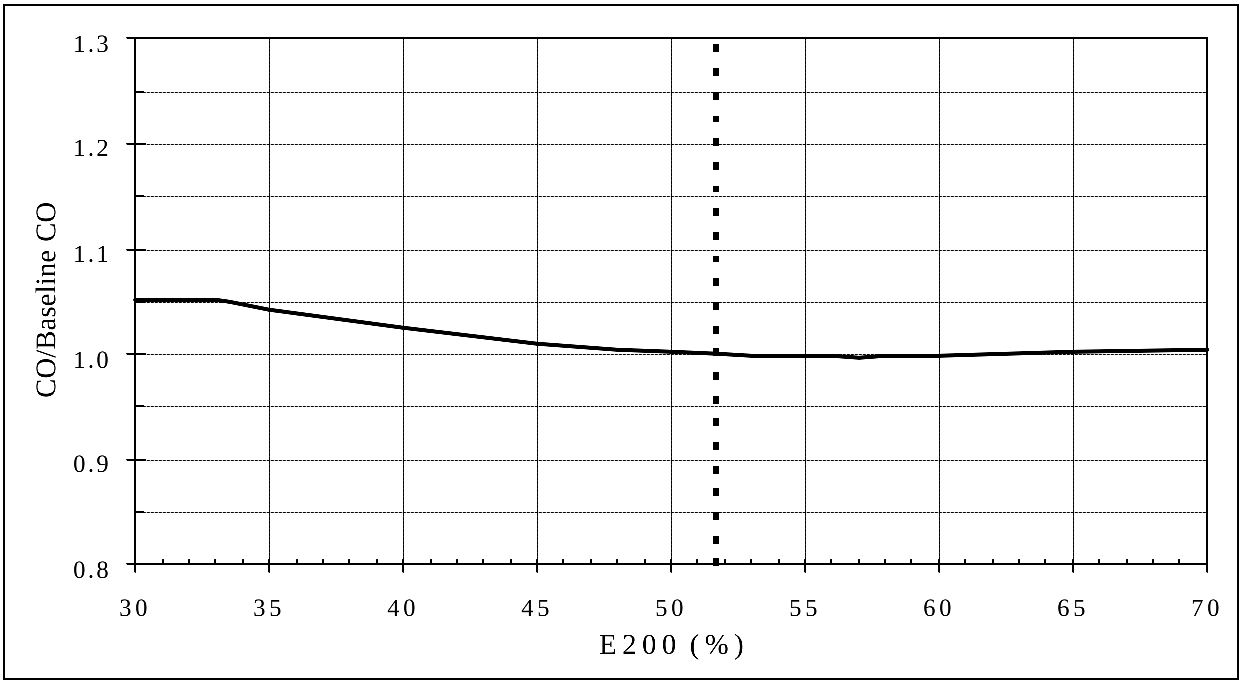

Exhibit C.5: CO Complex Model E200 Relationship

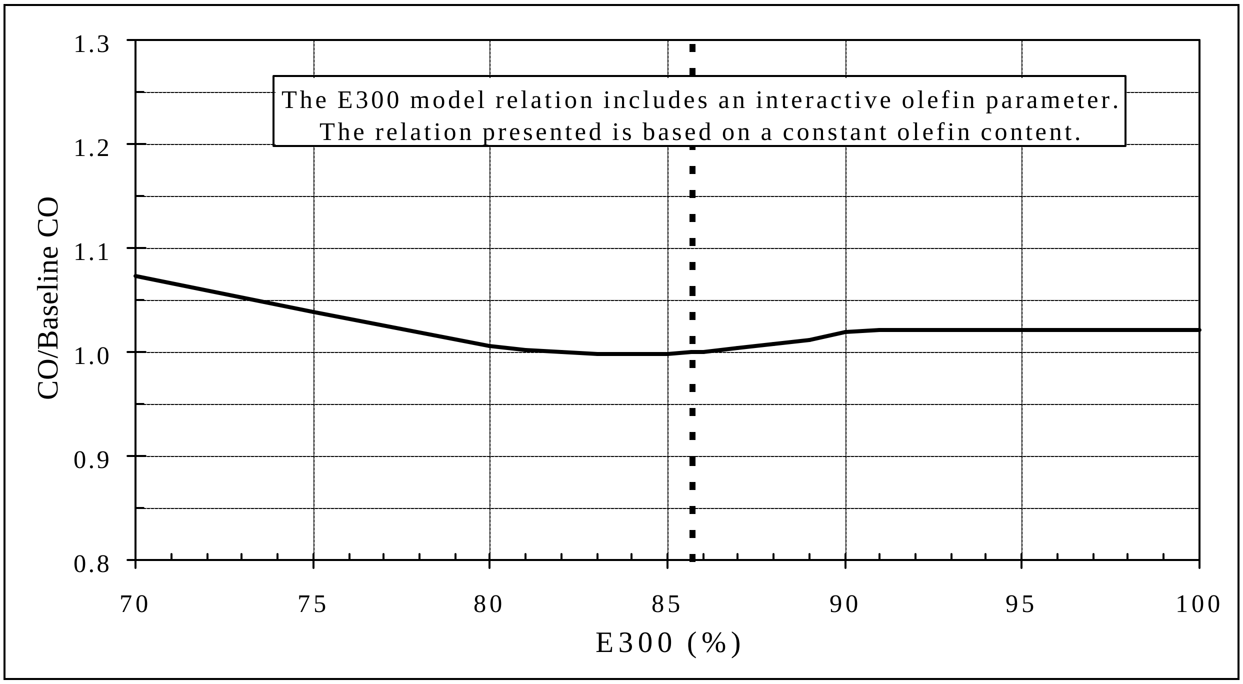

Exhibit C.6: CO Complex Model E300 Relationship

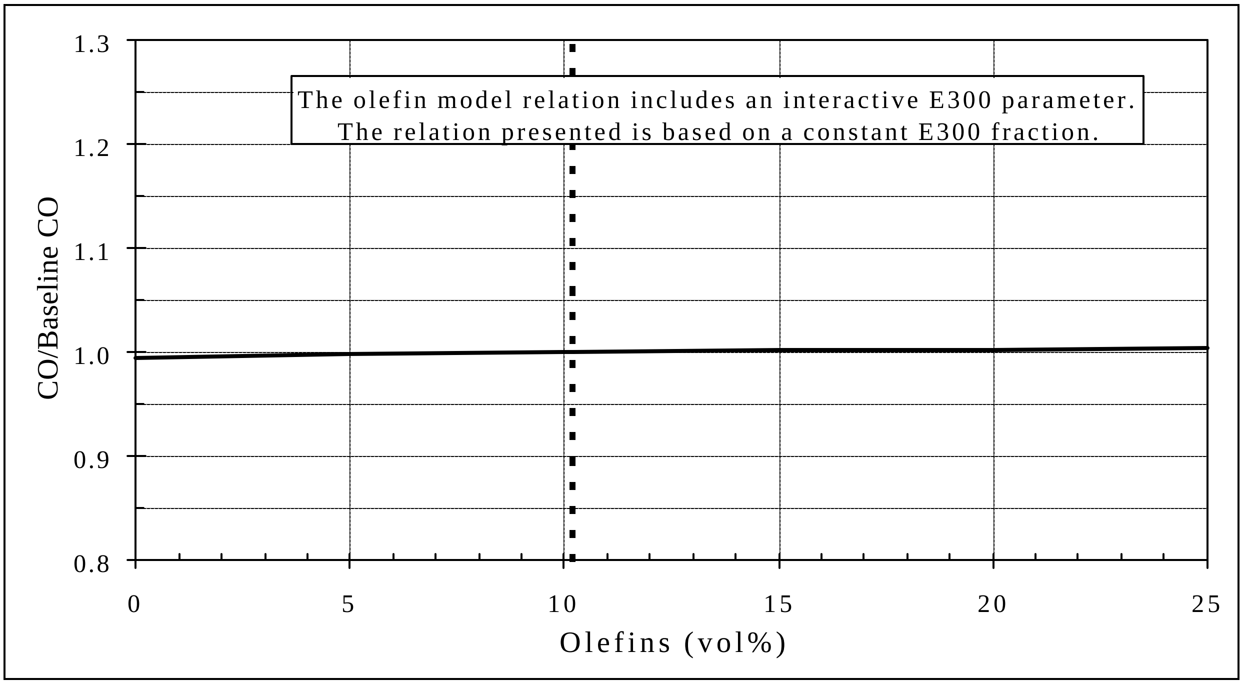

Exhibit C.7: CO Complex Model Olefin Content Relationship

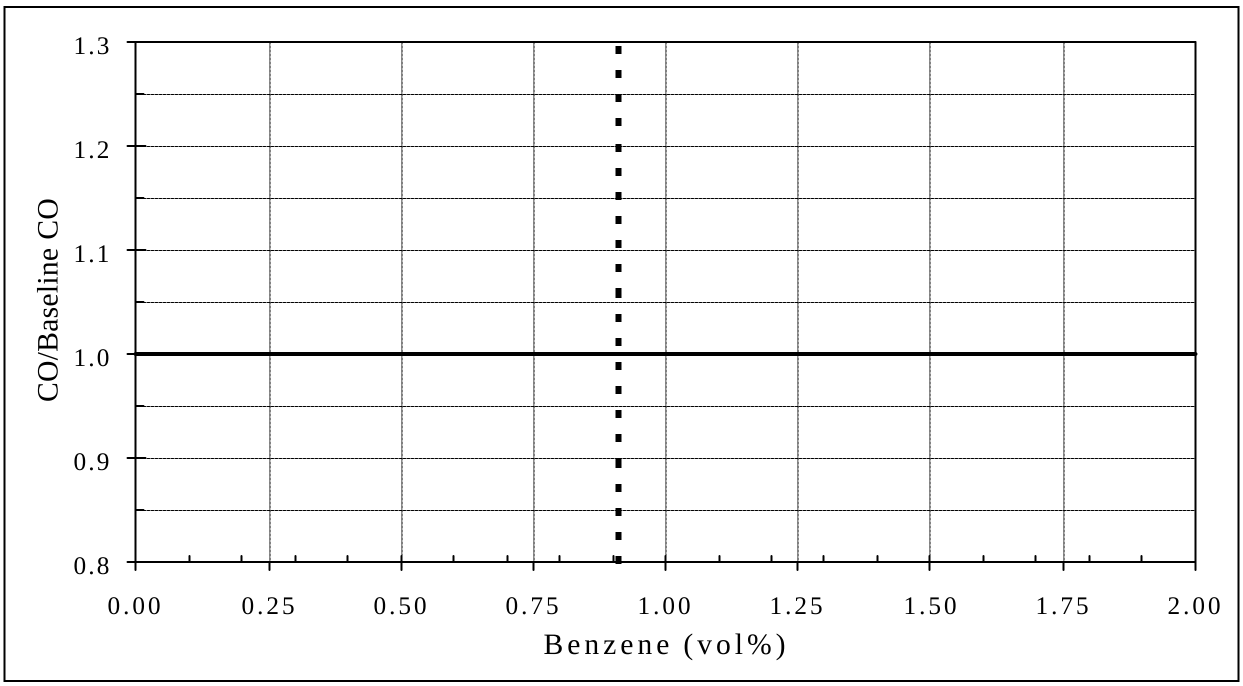

Exhibit C.8: CO Complex Model Benzene Content Relationship

APPENDIX D: TECHNOLOGY-SPECIFIC GASOLINE OPTION IMPACTS

As described in Section 5, alternative gasoline formulation analysis must be conducted at a catalyst technology level-of-detail. This approach to estimating both on- and off-road vehicle impacts is required because catalyst-equipped vehicles and engines can be expected to respond differently to fuel quality changes than their non-catalyst counterparts. Exhibits D.1 through D.3 present the catalyst technology-specific impacts estimated for each of the alternative gasoline formulations (as well as the estimated impact between the gasoline quality assumed for Maricopa County baseline emissions inventory modeling and actual gasoline qualities expected in the years evaluated for this analysis; see Section 5.4 for a detailed discussion of this adjustment) The non-catalyst technology impacts (Exhibit D.3) are used without further adjustment to estimate all gasoline formulation impacts on gasoline-powered off-road vehicles and engines. For on-road vehicles, the impacts presented in Exhibits D.1 through D.3 are aggregated in accordance with the market penetrations of each of the individual catalyst technologies in the applicable evaluation year.

Exhibit D.4 presents the catalyst technology weighting factors derived for each of the wintertime gasoline evaluation years. These technology fractions reflect both: (1) the market penetration of three-way catalyst vehicles, oxidation catalyst vehicles, and non-catalyst vehicles in the gasoline-powered passenger car, truck, and motorcycle fleets and (2) the VMT-weighted emissions performance of the applicable vehicles. In short, the tabulated values represent the fraction of total on-road gasoline vehicle *emissions* accumulated by vehicles of the various technologies. These technology fractions are applied to the individual technology impacts presented in Exhibits D.1 through D.3 to derive aggregate evaluation year impacts. Exhibits D.5 through D.7 present the resulting aggregate impacts.

As indicated in Section 5, the exhibits presented in this appendix also include a qualitative assessment of secondary organic PM impacts. This assessment is reflected in the *potential* secondary organic PM reduction relationships listed in each of the exhibits. However, it must be recognized that the tabulated secondary organic PM impact values are based solely on the relationship between fuel olefin and aromatic content and do *not* reflect any additional emissions impact factors. As such, these values are only indicative of *possible* secondary organic PM impacts.

Exhibit D.1: Three-Way Catalyst Emissions Impacts

Baseline Gasoline	Phoenix Modeling Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline
Candidate Gasoline	Actual Phoenix Winter Baseline	Winter Option 1 FedRFG2 80 ppmS	Winter Option 2 FedRFG2 30 ppmS	Winter Option 3 CalRFG2 2 wt%O	Winter Option 4 CalRFG2 3.5 wt%O	Winter Option 5 Perfrmnc Standard
Exhaust VOC	-5.8%	-1.4%	-2.6%	-1.6%	-2.4%	-2.4%
Evaporative VOC (1)						
NOx	-8.0%	-2.1%	-5.3%	-7.4%	-7.4%	-6.8%
CO	-8.8%	-0.9%	-4.5%	-3.1%	-7.0%	-6.2%
Exhaust Benzene	-20.3%	0.3%	-5.9%	-11.3%	-18.5%	-9.5%
Evaporative Benzene	-48.4%	5.5%	5.5%	-38.5%	-38.5%	5.5%
Acetaldehyde	-9.9%	-4.4%	-4.1%	-35.3%	-3.7%	-2.9%
Formaldehyde	-0.8%	-2.8%	0.8%	12.8%	12.7%	8.5%
Butadiene	-11.9%	-3.4%	-6.6%	-19.1%	-23.8%	-15.8%
Total Exhaust Toxics	-14.6%	-1.4%	-4.6%	-12.0%	-11.4%	-6.2%
Carbonaceous PM (2)						
Sulfate PM (2)						
Nitrate PM	-8.0%	-2.1%	-5.3%	-7.4%	-7.4%	-6.8%
Secondary Organic PM (3)	-0.5%	-0.8%	-8.4%	-29.4%	-29.4%	-21.0%
Sulfur Dioxide (2)						

(1) Determined directly on a technology-weighted basis using MOBILE5a.
(2) Determined directly on a technology-weighted basis using PART5.
(3) Impact not quantified, tabulated values are relative differences in the sum of fuel aromatics and olefins and should be only be used as a qualitative indicator of secondary organic PM potential.

Exhibit D.2: Oxidation Catalyst Emissions Impacts

Baseline Gasoline	Phoenix Modeling Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline
Candidate Gasoline	Actual Phoenix Winter Baseline	Winter Option 1 FedRFG2 80 ppmS	Winter Option 2 FedRFG2 30 ppmS	Winter Option 3 CalRFG2 2 wt%O	Winter Option 4 CalRFG2 3.5 wt%O	Winter Option 5 Perfrmnc Standard
Exhaust VOC	-5.8%	-1.4%	-2.6%	-1.6%	-2.4%	-2.4%
Evaporative VOC (1)						
NOx	-0.6%	-0.2%	-0.9%	-2.5%	-2.6%	-2.2%
CO	-8.8%	-0.9%	-4.5%	-3.1%	-7.0%	-6.2%
Exhaust Benzene	-20.3%	0.3%	-5.9%	-11.3%	-18.5%	-9.5%
Evaporative Benzene	-48.4%	5.5%	5.5%	-38.5%	-38.5%	5.5%
Acetaldehyde	-9.9%	-4.4%	-4.1%	-35.3%	-3.7%	-2.9%
Formaldehyde	-0.8%	-2.8%	0.8%	12.8%	12.7%	8.5%
Butadiene	-11.9%	-3.4%	-6.6%	-19.1%	-23.8%	-15.8%
Total Exhaust Toxics	-14.6%	-1.4%	-4.6%	-12.0%	-11.4%	-6.2%
Carbonaceous PM (2)						
Sulfate PM (2)						
Nitrate PM	-0.6%	-0.2%	-0.9%	-2.5%	-2.6%	-2.2%
Secondary Organic PM (3)	-0.5%	-0.8%	-8.4%	-29.4%	-29.4%	-21.0%
Sulfur Dioxide (2)						

(1) Determined directly on a technology-weighted basis using MOBILE5a.
(2) Determined directly on a technology-weighted basis using PART5.
(3) Impact not quantified, tabulated values are relative differences in the sum of fuel aromatics and olefins and should be only be used as a qualitative indicator of secondary organic PM potential.

Exhibit D.3: Non-Catalyst Vehicle and Off-Road Engine Emissions Impacts

Baseline Gasoline	Phoenix Modeling Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline
Candidate Gasoline	Actual Phoenix Winter Baseline	Winter Option 1 FedRFG2 80 ppmS	Winter Option 2 FedRFG2 30 ppmS	Winter Option 3 CalRFG2 2 wt%O	Winter Option 4 CalRFG2 3.5 wt%O	Winter Option 5 Perfrmnc Standard
Exhaust VOC	-1.8%	-0.7%	-1.1%	0.2%	-0.7%	-0.7%
Evaporative VOC	-7.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NOx	-0.6%	-0.2%	-0.9%	-2.5%	-2.6%	-2.2%
CO	0.5%	0.9%	-0.6%	1.4%	-2.7%	-2.1%
Exhaust Benzene	-11.4%	2.3%	-1.8%	-7.1%	-14.6%	-5.2%
Evaporative Benzene	-48.4%	5.5%	5.5%	-38.5%	-38.5%	5.5%
Acetaldehyde	-4.5%	-3.4%	-1.8%	-33.6%	-1.2%	-0.4%
Formaldehyde	-0.8%	-2.8%	0.8%	12.8%	12.7%	8.5%
Butadiene	-10.5%	-3.1%	-6.0%	-18.5%	-23.1%	-15.2%
Total Exhaust Toxics	-8.4%	-0.2%	-1.9%	-9.4%	-8.8%	-3.4%
Carbonaceous PM	-1.8%	-0.7%	-1.1%	0.2%	-0.7%	-0.7%
Sulfate PM	-64.5%	-33.3%	-75.0%	-83.3%	-83.3%	-80.0%
Nitrate PM	-0.6%	-0.2%	-0.9%	-2.5%	-2.6%	-2.2%
Secondary Organic PM (1)	-0.5%	-0.8%	-8.4%	-29.4%	-29.4%	-21.0%
Sulfur Dioxide	-64.5%	-33.3%	-75.0%	-83.3%	-83.3%	-80.0%

(1) Impact not quantified, tabulated values are relative differences in the sum of fuel aromatics and olefins and should be only be used as a qualitative indicator of secondary organic PM potential.

Exhibit D.4: On-Road Gasoline Vehicle VMT-Weighted Technology Fractions

Evaluation Year	No Catalyst	Oxidation Catalyst	Three-Way Catalyst
2001	0.0298	0.0640	0.9061
2004	0.0247	0.0524	0.9229
2010	0.0214	0.0400	0.9386

Consolidates LDGV, LDGT1, LDGT2, HDGV, and MC technologies.

Exhibit D.5: Aggregate 2001 On-Road Vehicle Emissions Impacts

Baseline Gasoline	Phoenix Modeling Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline
Candidate Gasoline	Actual Phoenix Winter Baseline	Winter Option 1 FedRFG2 80 ppmS	Winter Option 2 FedRFG2 30 ppmS	Winter Option 3 CalRFG2 2 wt%O	Winter Option 4 CalRFG2 3.5 wt%O	Winter Option 5 Perfrmnc Standard
Exhaust VOC	-5.7%	-1.4%	-2.6%	-1.5%	-2.4%	-2.3%
Evaporative VOC	-4.2%	0.0%	0.0%	0.0%	0.0%	0.0%
NOx	-7.3%	-1.9%	-4.9%	-6.9%	-7.0%	-6.4%
CO	-8.6%	-0.8%	-4.4%	-3.0%	-6.9%	-6.1%
Exhaust Benzene	-20.0%	0.4%	-5.8%	-11.2%	-18.4%	-9.3%
Evaporative Benzene	-48.4%	5.5%	5.5%	-38.5%	-38.5%	5.5%
Acetaldehyde	-9.7%	-4.4%	-4.0%	-35.3%	-3.7%	-2.8%
Formaldehyde	-0.8%	-2.8%	0.8%	12.8%	12.7%	8.5%
Butadiene	-11.9%	-3.4%	-6.6%	-19.1%	-23.7%	-15.8%
Total Exhaust Toxics	-14.4%	-1.4%	-4.5%	-11.9%	-11.3%	-6.1%
Carbonaceous PM	-3.6%	-0.9%	-1.6%	-0.9%	-1.4%	-1.4%
Sulfate PM	-42.6%	-23.2%	-52.3%	-58.1%	-58.1%	-55.8%
Nitrate PM	-7.3%	-1.9%	-4.9%	-6.9%	-7.0%	-6.4%
Secondary Organic PM (1)	-0.5%	-0.8%	-8.4%	-29.4%	-29.4%	-21.0%
Sulfur Dioxide	-66.6%	-36.3%	-81.7%	-90.8%	-90.8%	-87.1%

(1) Impact not quantified, tabulated values are relative differences in the sum of fuel aromatics and olefins and should be only be used as a qualitative indicator of secondary organic PM potential.

Exhibit D.6: Aggregate 2004 On-Road Vehicle Emissions Impacts

Baseline Gasoline	Phoenix Modeling Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline
Candidate Gasoline	Actual Phoenix Winter Baseline	Winter Option 1 FedRFG2 80 ppmS	Winter Option 2 FedRFG2 30 ppmS	Winter Option 3 CalRFG2 2 wt%O	Winter Option 4 CalRFG2 3.5 wt%O	Winter Option 5 Perfrmnc Standard
Exhaust VOC	-5.7%	-1.4%	-2.6%	-1.5%	-2.4%	-2.3%
Evaporative VOC	-4.4%	0.0%	0.0%	0.0%	0.0%	0.0%
NOx	-7.4%	-2.0%	-5.0%	-7.0%	-7.0%	-6.5%
CO	-8.6%	-0.8%	-4.4%	-3.0%	-6.9%	-6.1%
Exhaust Benzene	-20.1%	0.4%	-5.8%	-11.2%	-18.4%	-9.4%
Evaporative Benzene	-48.4%	5.5%	5.5%	-38.5%	-38.5%	5.5%
Acetaldehyde	-9.7%	-4.4%	-4.0%	-35.3%	-3.7%	-2.8%
Formaldehyde	-0.8%	-2.8%	0.8%	12.8%	12.7%	8.5%
Butadiene	-11.9%	-3.4%	-6.6%	-19.1%	-23.7%	-15.8%
Total Exhaust Toxics	-14.5%	-1.4%	-4.5%	-11.9%	-11.3%	-6.1%
Carbonaceous PM	-4.1%	-1.0%	-1.9%	-1.1%	-1.7%	-1.7%
Sulfate PM	-42.7%	-23.2%	-52.3%	-58.1%	-58.1%	-55.8%
Nitrate PM	-7.4%	-2.0%	-5.0%	-7.0%	-7.0%	-6.5%
Secondary Organic PM (1)	-0.5%	-0.8%	-8.4%	-29.4%	-29.4%	-21.0%
Sulfur Dioxide	-66.6%	-36.3%	-81.7%	-90.8%	-90.8%	-87.1%

(1) Impact not quantified, tabulated values are relative differences in the sum of fuel aromatics and olefins and should be only be used as a qualitative indicator of secondary organic PM potential.

Exhibit D.7: Aggregate 2010 On-Road Vehicle Emissions Impacts

Baseline Gasoline	Phoenix Modeling Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline	Actual Phoenix Winter Baseline
Candidate Gasoline	Actual Phoenix Winter Baseline	Winter Option 1 FedRFG2 80 ppmS	Winter Option 2 FedRFG2 30 ppmS	Winter Option 3 CalRFG2 2 wt%O	Winter Option 4 CalRFG2 3.5 wt%O	Winter Option 5 Perfrmnc Standard
Exhaust VOC	-5.8%	-1.4%	-2.6%	-1.5%	-2.4%	-2.3%
Evaporative VOC	-6.6%	0.0%	0.0%	0.0%	0.0%	0.0%
NOx	-7.6%	-2.0%	-5.1%	-7.1%	-7.1%	-6.6%
CO	-8.6%	-0.8%	-4.4%	-3.0%	-6.9%	-6.1%
Exhaust Benzene	-20.1%	0.4%	-5.9%	-11.2%	-18.5%	-9.4%
Evaporative Benzene	-48.4%	5.5%	5.5%	-38.5%	-38.5%	5.5%
Acetaldehyde	-9.7%	-4.4%	-4.1%	-35.3%	-3.7%	-2.8%
Formaldehyde	-0.8%	-2.8%	0.8%	12.8%	12.7%	8.5%
Butadiene	-11.9%	-3.4%	-6.6%	-19.1%	-23.7%	-15.8%
Total Exhaust Toxics	-14.5%	-1.4%	-4.5%	-11.9%	-11.3%	-6.1%
Carbonaceous PM	-4.5%	-1.1%	-2.1%	-1.3%	-1.9%	-1.9%
Sulfate PM	-42.6%	-23.2%	-52.3%	-58.1%	-58.1%	-55.7%
Nitrate PM	-7.6%	-2.0%	-5.1%	-7.1%	-7.1%	-6.6%
Secondary Organic PM (1)	-0.5%	-0.8%	-8.4%	-29.4%	-29.4%	-21.0%
Sulfur Dioxide	-66.6%	-36.3%	-81.7%	-90.7%	-90.7%	-87.1%

(1) Impact not quantified, tabulated values are relative differences in the sum of fuel aromatics and olefins and should be only be used as a qualitative indicator of secondary organic PM potential.

APPENDIX E: KEY EMISSION REDUCTIONS OF GASOLINE OPTIONS

This appendix presents a series of graphics illustrating the relative emissions reductions for the various gasoline formulation options evaluated in this study. Since VOC and NO_x emissions are primarily of interest during the summer months due to their impact on ozone formation, an impact which cannot be influenced by wintertime gasoline formulations, the VOC and NO_x impacts of the various wintertime gasoline formulations evaluated in this study are not presented in this appendix. Moreover, because the bulk of gasoline PM-related impacts accrue through reductions in sulfate particulate, graphics for only sulfate and total PM impacts are presented.

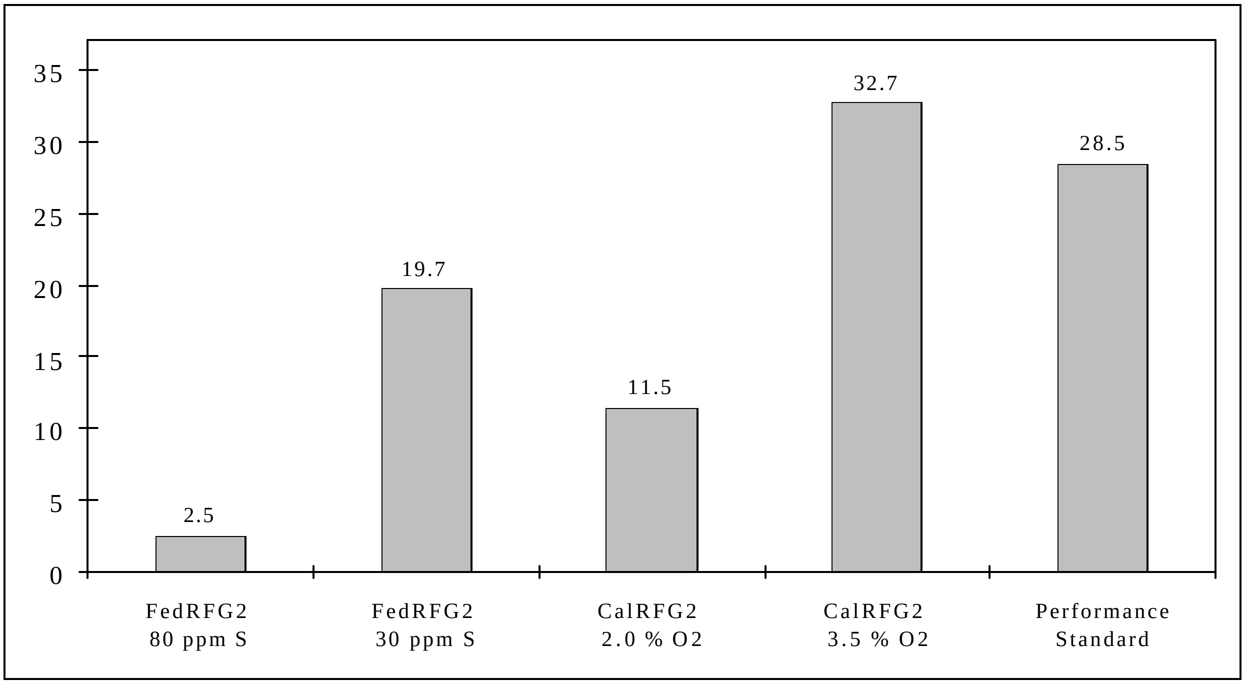

Exhibit E.1: Wintertime CO Reductions in 2001 (metric tons per day)

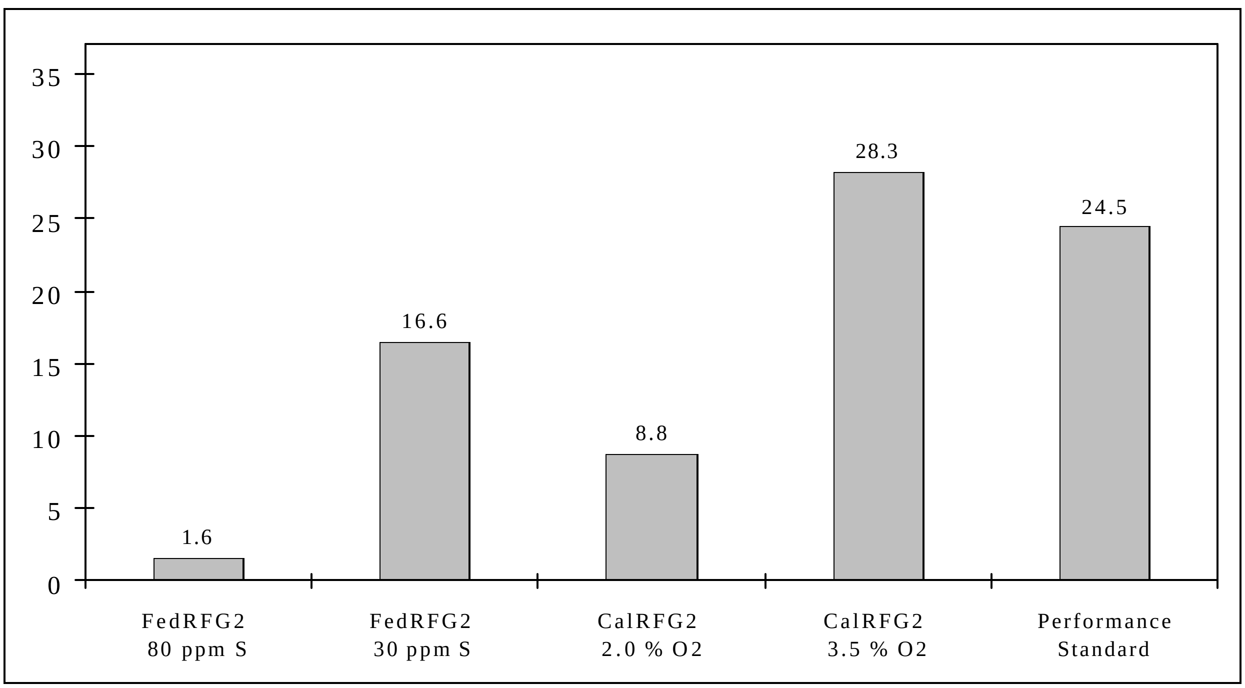

Exhibit E.2: Wintertime CO Reductions in 2010 (metric tons per day)

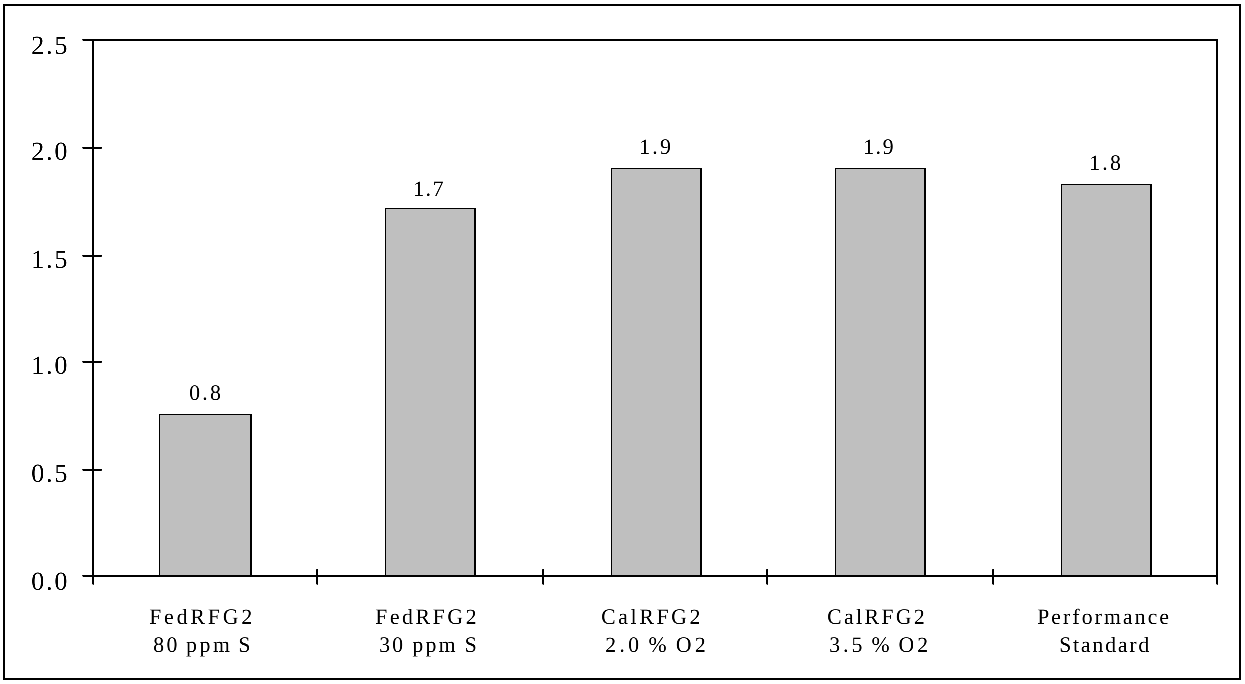

Exhibit E.3: Wintertime Sulfate PM-10 Reductions in 2004 (metric tons per day)

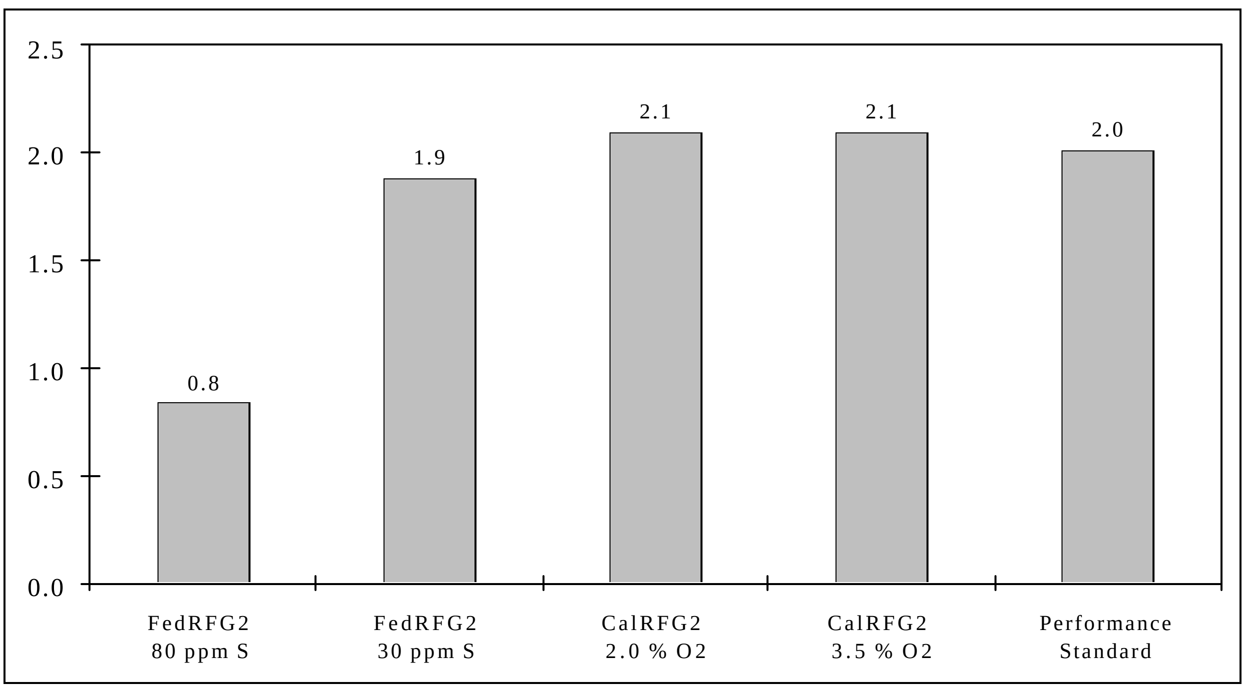

Exhibit E.4: Wintertime Sulfate PM-10 Reductions in 2010 (metric tons per day)

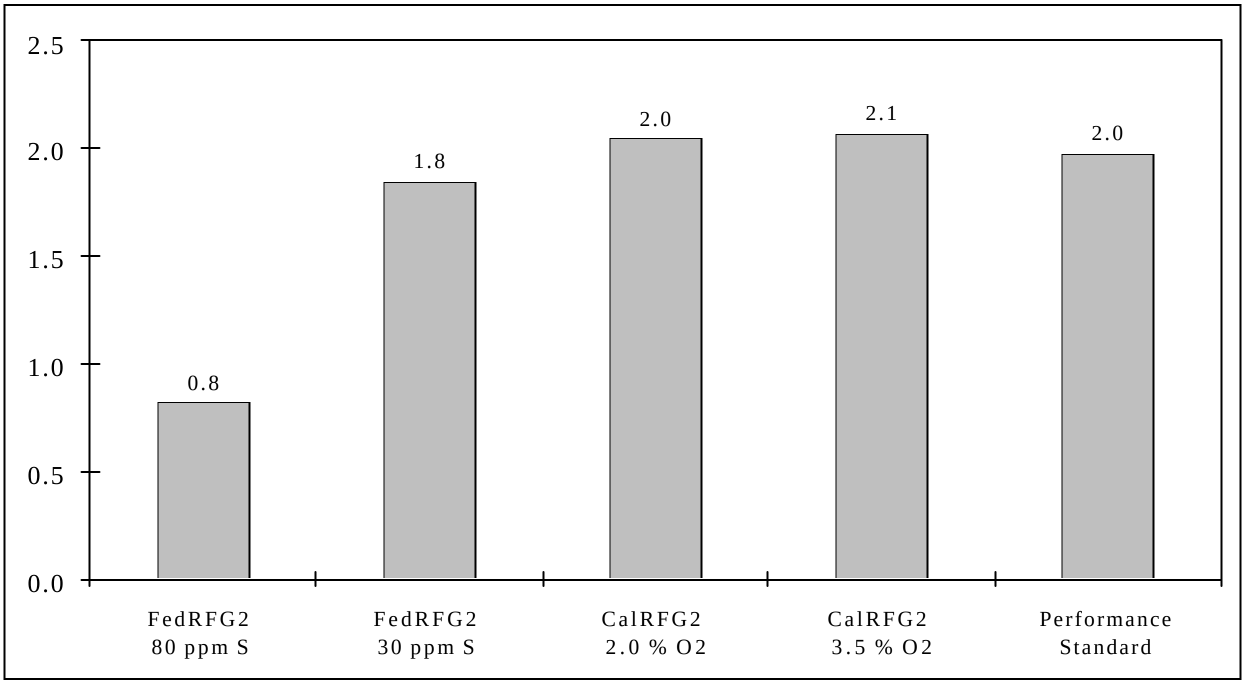

Exhibit E.5: Wintertime Total PM-10 Reductions in 2004 (metric tons per day)

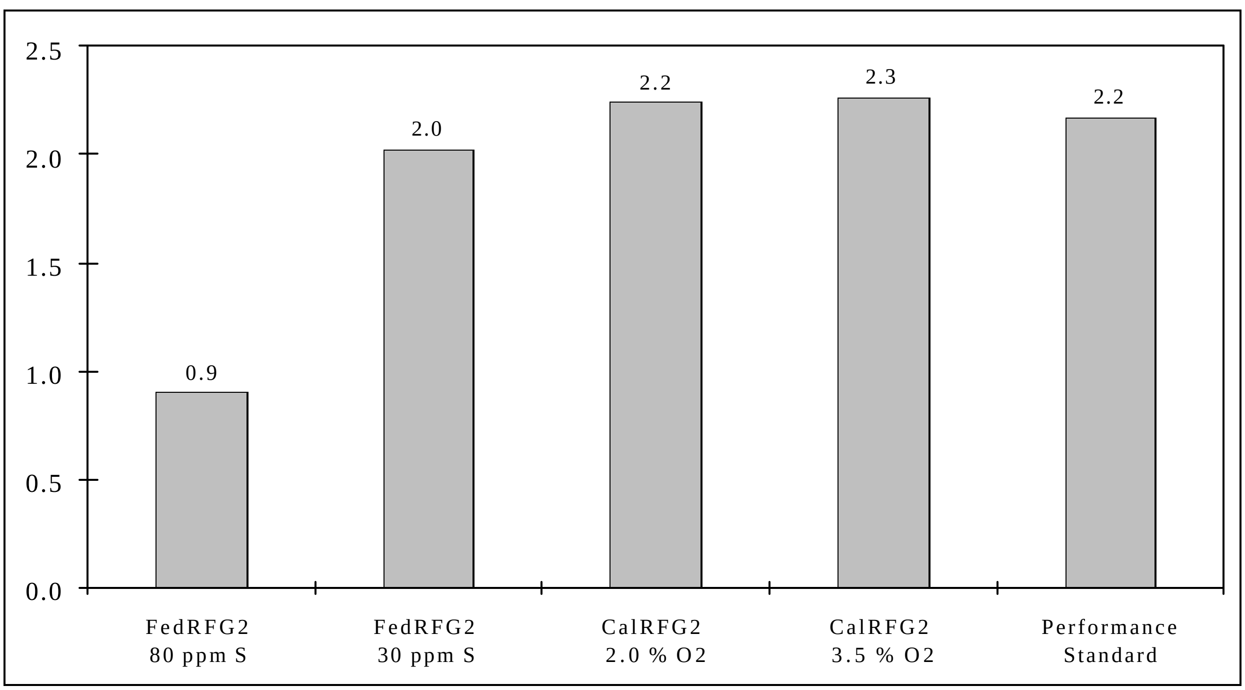

Exhibit E.6: Wintertime Total PM-10 Reductions in 2010 (metric tons per day)

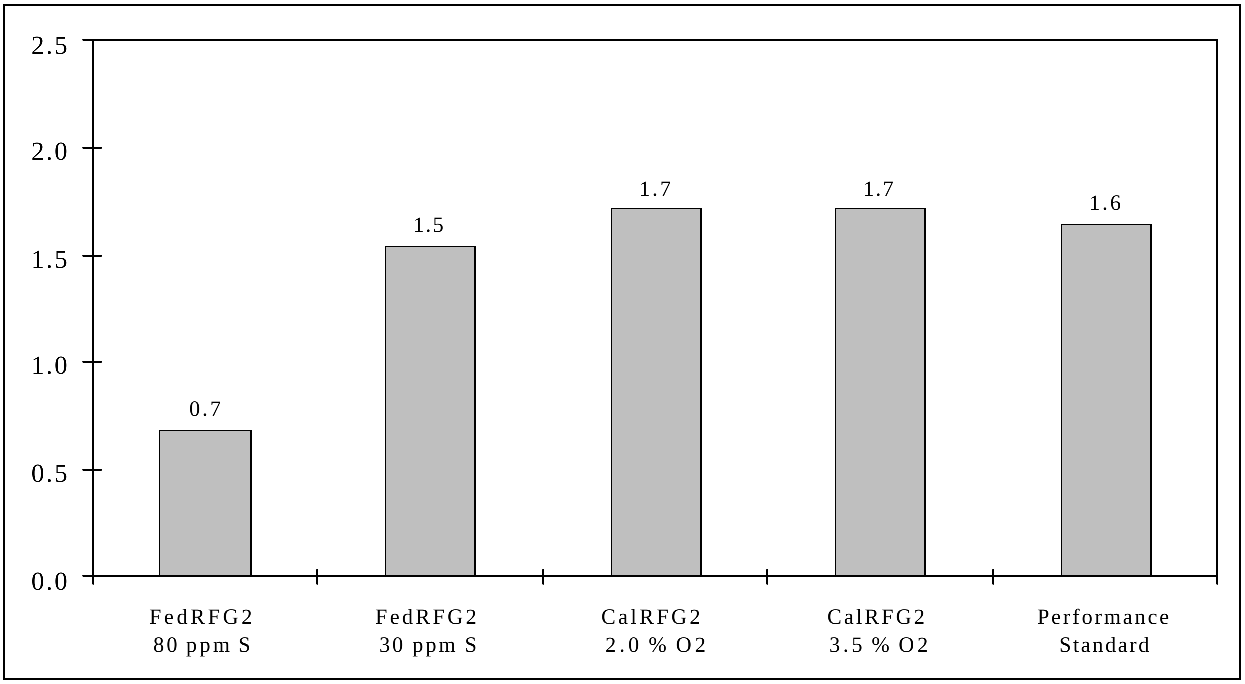

Exhibit E.7: Wintertime Sulfate PM-2.5 Reductions in 2004 (metric tons per day)

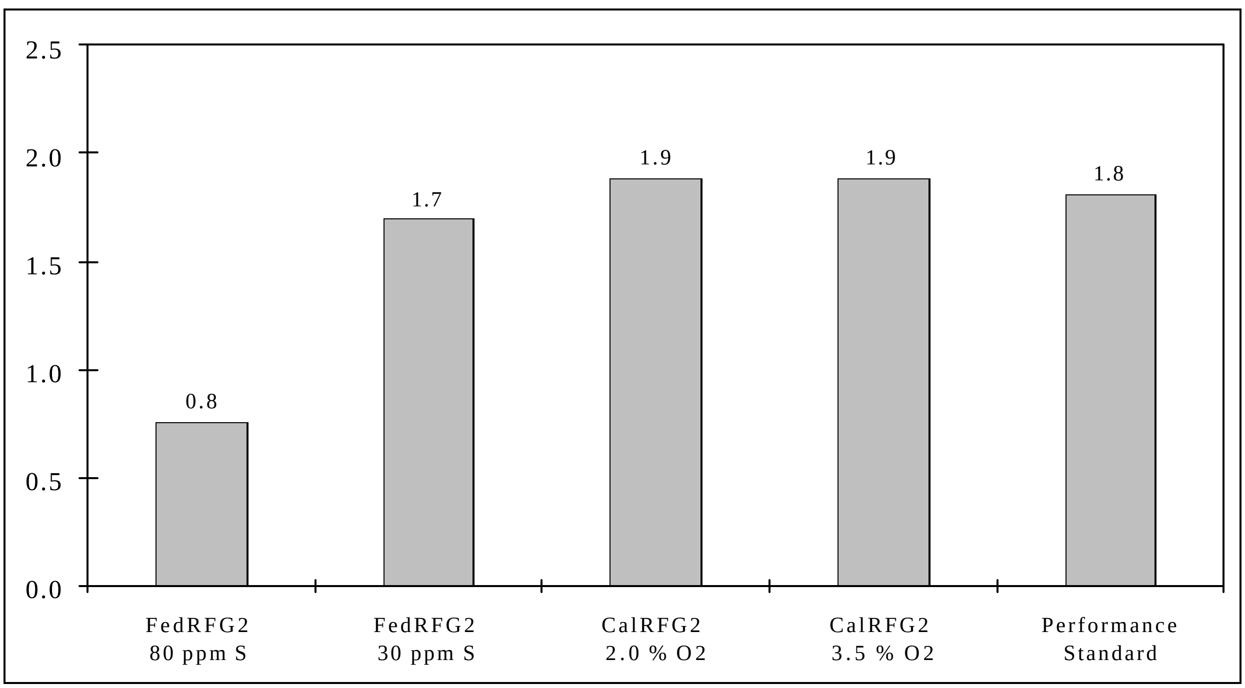

Exhibit E.8: Wintertime Sulfate PM-2.5 Reductions in 2010 (metric tons per day)

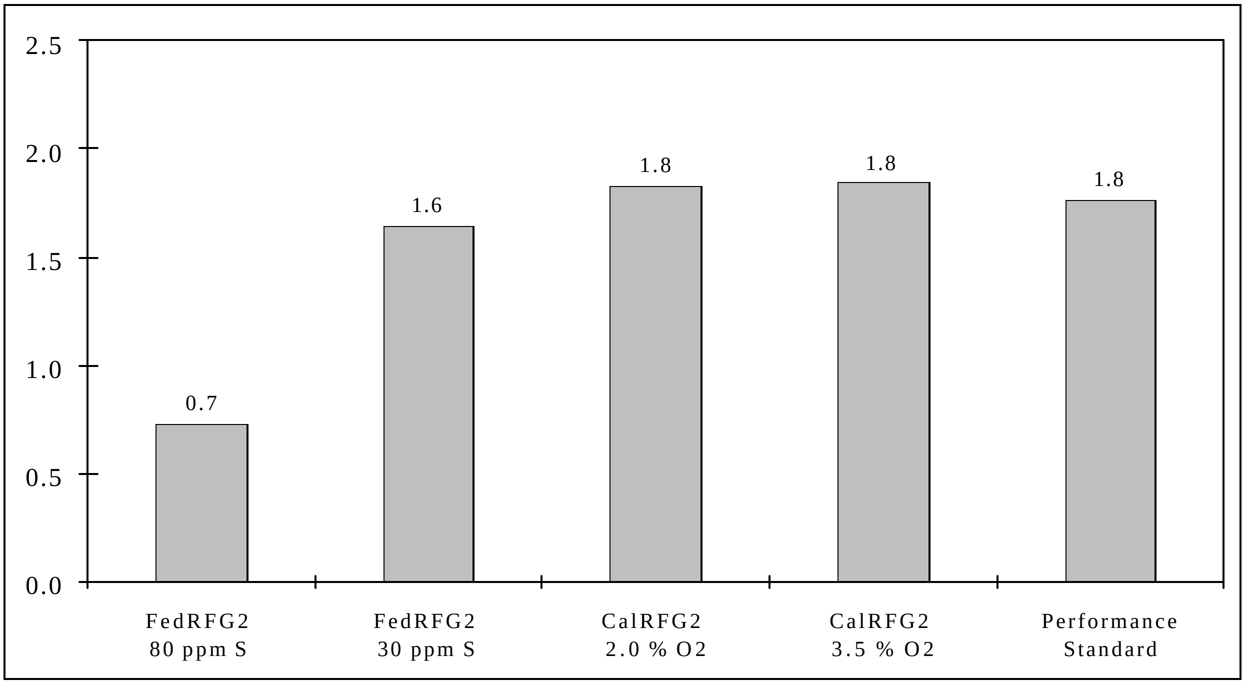

Exhibit E.9: Wintertime Total PM-2.5 Reductions in 2004 (metric tons per day)

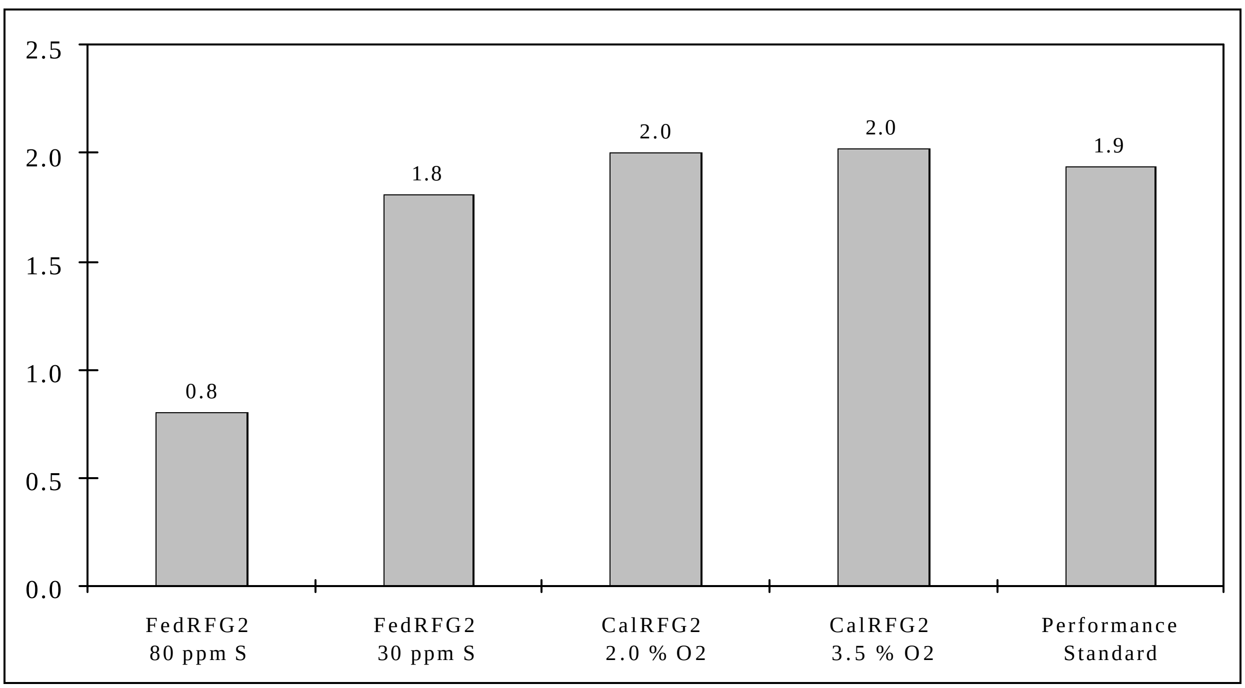

Exhibit E.10: Wintertime Total PM-2.5 Reductions in 2010 (metric tons per day)

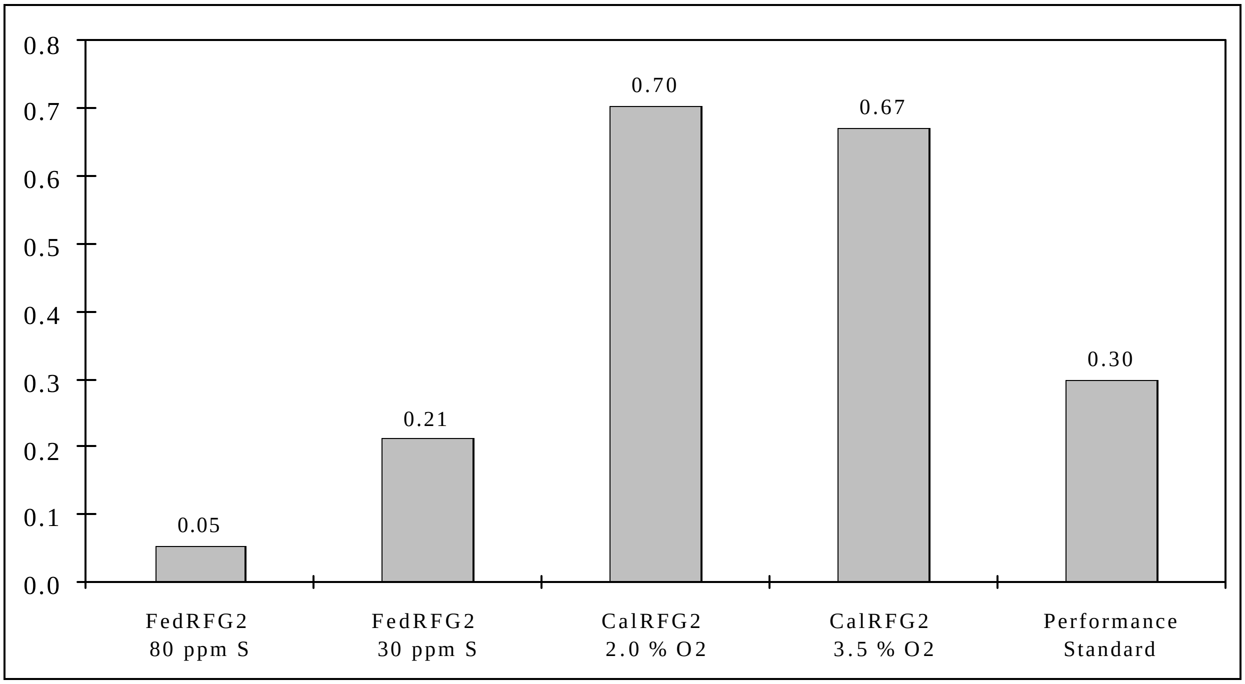

Exhibit E.11: Wintertime Toxic Reductions in 2004 (metric tons per day)

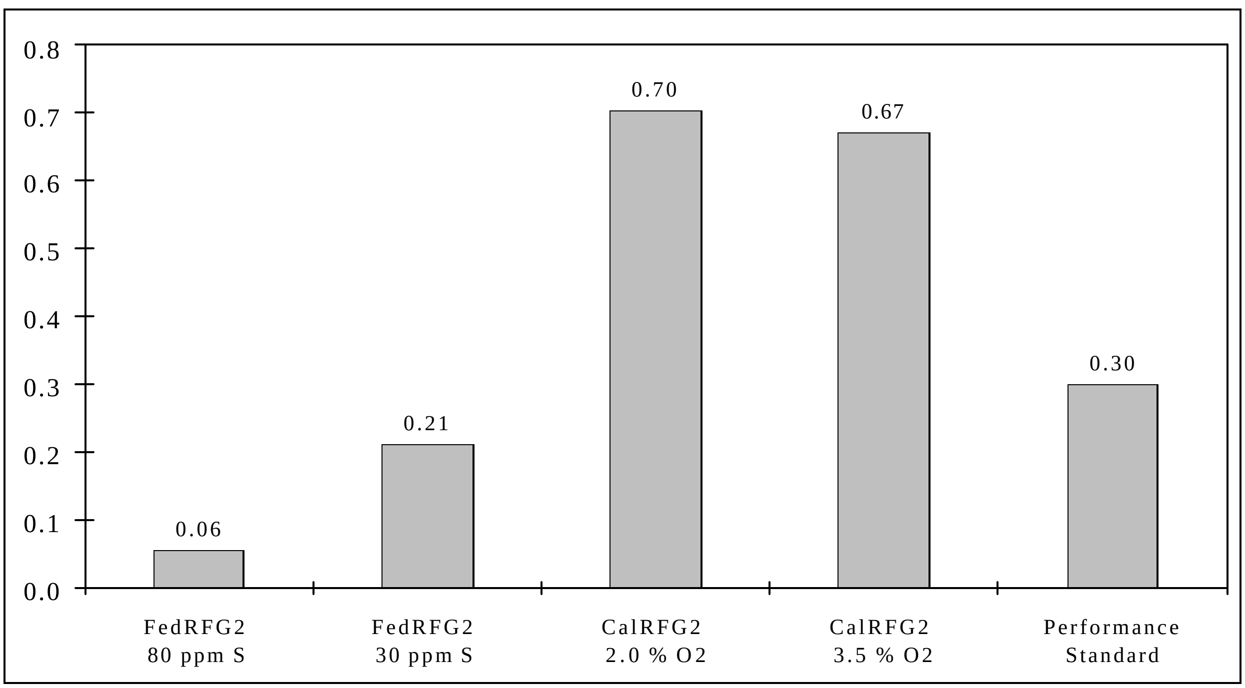

Exhibit E.12: Wintertime Toxic Reductions in 2010 (metric tons per day)

APPENDIX F: PERCENTAGE CHANGE IN MARICOPA COUNTY INVENTORIES

This appendix consists of a series of tables which express the emission reductions for each of the gasoline options presented in Section 6 in terms of the effective percentage change in the corresponding Maricopa County emissions inventories. Exhibits F.1A and F.1B present the effective percentage reduction in the total (i.e., all emission sources considered) applicable emissions inventory. Exhibits F.2A and F.2B present percentage reductions in applicable on-road emission inventories. Exhibits F.3A and F.3B present percentage reductions in applicable off-road emission inventories. Finally, Exhibits F.4A and F.4B present percentage reductions in overall mobile source (i.e., on-road plus off-road) emission inventories.

Nothing in these exhibits affects the previously presented (Section 6) rank order emission reduction effectiveness of the various gasoline options evaluated. These exhibits do, however, provide insight into the relative significance of the estimated emission reductions through comparison to the overall Maricopa County emissions inventories for various affected source categories.

Exhibit F.1A: Gasoline Option Impacts on Total (i.e., All Sources) Maricopa County Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2001 (January 1)					
Wintertime CO	0.4%	3.2%	1.9%	5.3%	4.7%
Calendar Year 2004 (January 1)					
Wintertime VOC	0.4%	0.7%	0.4%	0.6%	0.6%
Wintertime NO_x	1.1%	2.8%	3.9%	3.9%	3.6%
Carbonaceous PM-10	0.0%	0.0%	0.0%	0.0%	0.0%
Sulfate PM-10	3.9%	8.8%	9.8%	9.8%	9.4%
Nitrate PM-10	1.1%	2.8%	3.9%	3.9%	3.6%
Total PM-10	0.4%	0.9%	1.0%	1.0%	1.0%
Carbonaceous PM-2.5	0.0%	0.0%	0.0%	0.0%	0.0%
Sulfate PM-2.5	3.9%	8.8%	9.8%	9.8%	9.4%
Nitrate PM-2.5	1.1%	2.8%	3.9%	3.9%	3.6%
Total PM-2.5	0.7%	1.5%	1.7%	1.7%	1.6%
Benzene	n/e	n/e	n/e	n/e	n/e
1,3-Butadiene	n/e	n/e	n/e	n/e	n/e
Formaldehyde	n/e	n/e	n/e	n/e	n/e
Acetaldehyde	n/e	n/e	n/e	n/e	n/e
Total Toxics	n/e	n/e	n/e	n/e	n/e
Potency-Weighted Toxics	n/e	n/e	n/e	n/e	n/e

"n/e" indicates that "no estimate" was possible. Data for the non-mobile source contribution to the total Maricopa County toxic emission inventory was not provided.

Exhibit F.1B: Gasoline Option Impacts on Total (i.e., All Sources) Maricopa County Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2010 (January 1)					
Wintertime CO	0.3%	2.9%	1.5%	4.9%	4.3%
Wintertime VOC	0.4%	0.7%	0.4%	0.6%	0.6%
Wintertime NO_x	1.1%	2.8%	3.9%	3.9%	3.6%
Carbonaceous PM-10	0.0%	0.0%	0.0%	0.0%	0.0%
Sulfate PM-10	3.9%	8.8%	9.8%	9.8%	9.4%
Nitrate PM-10	1.1%	2.8%	3.9%	3.9%	3.6%
Total PM-10	0.4%	1.0%	1.1%	1.1%	1.0%
Carbonaceous PM-2.5	0.0%	0.0%	0.0%	0.0%	0.0%
Sulfate PM-2.5	3.9%	8.8%	9.8%	9.8%	9.4%
Nitrate PM-2.5	1.1%	2.8%	3.9%	3.9%	3.6%
Total PM-2.5	0.7%	1.6%	1.8%	1.8%	1.7%
Benzene	n/e	n/e	n/e	n/e	n/e
1,3-Butadiene	n/e	n/e	n/e	n/e	n/e
Formaldehyde	n/e	n/e	n/e	n/e	n/e
Acetaldehyde	n/e	n/e	n/e	n/e	n/e
Total Toxics	n/e	n/e	n/e	n/e	n/e
Potency-Weighted Toxics	n/e	n/e	n/e	n/e	n/e

"n/e" indicates that "no estimate" was possible. Data for the non-mobile source contribution to the total Maricopa County toxic emission inventory was not provided.

Exhibit F.2A: Gasoline Option Impacts on Maricopa County On-Road Vehicle Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2001 (January 1)					
Wintertime CO	0.7%	4.1%	2.8%	6.4%	5.7%
Calendar Year 2004 (January 1)					
Wintertime VOC	1.0%	1.9%	1.1%	1.7%	1.7%
Wintertime NO_x	1.4%	3.6%	5.0%	5.1%	4.7%
Carbonaceous PM-10	0.2%	0.4%	0.2%	0.3%	0.3%
Sulfate PM-10	14.1%	31.8%	35.3%	35.3%	33.9%
Nitrate PM-10	1.4%	3.6%	5.0%	5.1%	4.7%
Total PM-10	5.3%	12.1%	13.7%	13.7%	13.1%
Carbonaceous PM-2.5	0.2%	0.3%	0.2%	0.3%	0.3%
Sulfate PM-2.5	14.1%	31.8%	35.3%	35.3%	33.9%
Nitrate PM-2.5	1.4%	3.6%	5.0%	5.1%	4.7%
Total PM-2.5	5.5%	12.4%	14.0%	14.1%	13.4%
Benzene[1]	-0.7%	5.1%	13.0%	19.8%	8.4%
1,3-Butadiene[1]	3.4%	6.6%	19.1%	23.7%	15.8%
Formaldehyde[1]	2.8%	-0.8%	-12.8%	-12.7%	-8.5%
Acetaldehyde[1]	4.4%	4.0%	35.3%	3.7%	2.8%
Total Toxics[1]	1.2%	4.2%	13.3%	12.7%	5.8%
Potency-Weighted Toxics[1]	3.4%	7.5%	21.4%	26.7%	17.0%

[1] Impacts reflect percentage reduction in on-road gasoline emissions only.

Exhibit F.2B: Gasoline Option Impacts on Maricopa County On-Road Vehicle Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2010 (January 1)					
Wintertime CO	0.7%	4.1%	2.8%	6.3%	5.6%
Wintertime VOC	1.0%	1.9%	1.1%	1.7%	1.7%
Wintertime NO_x	1.4%	3.7%	5.1%	5.2%	4.8%
Carbonaceous PM-10	0.2%	0.5%	0.3%	0.4%	0.4%
Sulfate PM-10	14.0%	31.5%	35.0%	35.0%	33.6%
Nitrate PM-10	1.4%	3.7%	5.1%	5.2%	4.8%
Total PM-10	5.7%	12.8%	14.6%	14.6%	14.0%
Carbonaceous PM-2.5	0.2%	0.5%	0.3%	0.4%	0.4%
Sulfate PM-2.5	14.0%	31.5%	35.0%	35.0%	33.6%
Nitrate PM-2.5	1.4%	3.7%	5.1%	5.2%	4.8%
Total PM-2.5	5.8%	13.2%	15.0%	15.0%	14.4%
Benzene[1]	-0.7%	5.1%	13.0%	19.8%	8.4%
1,3-Butadiene[1]	3.4%	6.6%	19.1%	23.7%	15.8%
Formaldehyde[1]	2.8%	-0.8%	-12.8%	-12.7%	-8.5%
Acetaldehyde[1]	4.4%	4.1%	35.3%	3.7%	2.8%
Total Toxics[1]	1.2%	4.2%	13.4%	12.8%	5.8%
Potency-Weighted Toxics[1]	3.4%	7.5%	21.4%	26.7%	17.0%

[1] Impacts reflect percentage reduction in on-road gasoline emissions only.

Exhibit F.3A: Gasoline Option Impacts on Maricopa County Off-Road Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2001 (January 1)					
Wintertime CO	-0.7%	0.5%	-1.1%	2.1%	1.6%
Calendar Year 2004 (January 1)					
Wintertime VOC	0.3%	0.5%	-0.1%	0.3%	0.3%
Wintertime NO_x	0.0%	0.0%	0.1%	0.1%	0.1%
Carbonaceous PM-10	0.1%	0.2%	0.0%	0.1%	0.1%
Sulfate PM-10	10.6%	23.9%	26.5%	26.5%	25.4%
Nitrate PM-10	0.0%	0.0%	0.1%	0.1%	0.1%
Total PM-10	2.5%	5.6%	6.0%	6.1%	5.9%
Carbonaceous PM-2.5	0.1%	0.2%	0.0%	0.1%	0.1%
Sulfate PM-2.5	10.6%	23.9%	26.5%	26.5%	25.4%
Nitrate PM-2.5	0.0%	0.0%	0.1%	0.1%	0.1%
Total PM-2.5	2.5%	5.6%	6.1%	6.2%	5.9%
Benzene[1]	-2.5%	1.4%	9.0%	16.0%	4.6%
1,3-Butadiene[1]	2.8%	5.3%	16.5%	20.6%	13.5%
Formaldehyde[1]	2.5%	-0.7%	-11.5%	-11.4%	-7.7%
Acetaldehyde[1]	3.1%	1.6%	30.1%	1.1%	0.4%
Total Toxics[1]	-0.1%	1.6%	10.4%	10.0%	3.2%
Potency-Weighted Toxics[1]	2.5%	5.6%	18.1%	23.0%	14.0%

1 Impacts reflect percentage reduction in on-road gasoline emissions only.

Exhibit F.3B: Gasoline Option Impacts on Maricopa County Off-Road Emission Inventories (Percent Reduction)					
Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2010 (January 1)					
Wintertime CO	-0.7%	0.5%	-1.1%	2.1%	1.6%
Wintertime VOC	0.2%	0.4%	-0.1%	0.2%	0.2%
Wintertime NO_x	0.0%	0.0%	0.1%	0.1%	0.1%
Carbonaceous PM-10	0.1%	0.2%	0.0%	0.1%	0.1%
Sulfate PM-10	8.7%	19.5%	21.7%	21.7%	20.8%
Nitrate PM-10	0.0%	0.0%	0.1%	0.1%	0.1%
Total PM-10	2.2%	4.8%	5.2%	5.3%	5.1%
Carbonaceous PM-2.5	0.1%	0.2%	0.0%	0.1%	0.1%
Sulfate PM-2.5	8.7%	19.5%	21.7%	21.7%	20.8%
Nitrate PM-2.5	0.0%	0.0%	0.1%	0.1%	0.1%
Total PM-2.5	2.2%	4.8%	5.2%	5.3%	5.1%
Benzene[1]	-2.5%	1.4%	9.0%	16.0%	4.6%
1,3-Butadiene[1]	2.8%	5.3%	16.5%	20.6%	13.5%
Formaldehyde[1]	2.5%	-0.7%	-11.5%	-11.4%	-7.7%
Acetaldehyde[1]	3.1%	1.6%	30.1%	1.1%	0.4%
Total Toxics[1]	-0.1%	1.6%	10.4%	10.0%	3.2%
Potency-Weighted Toxics[1]	2.5%	5.6%	18.1%	23.0%	14.0%

[1] Impacts reflect percentage reduction in on-road gasoline emissions only.

Exhibit F.4A: Gasoline Option Impacts on Maricopa County Mobile Source (On-Road plus Off-Road) Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2001 (January 1)					
Wintertime CO	0.4%	3.3%	1.9%	5.4%	4.7%
Calendar Year 2004 (January 1)					
Wintertime VOC	0.9%	1.7%	0.9%	1.5%	1.5%
Wintertime NO_x	1.2%	3.2%	4.5%	4.5%	4.1%
Carbonaceous PM-10	0.1%	0.2%	0.0%	0.2%	0.2%
Sulfate PM-10	12.3%	27.6%	30.7%	30.7%	29.4%
Nitrate PM-10	1.2%	3.2%	4.4%	4.5%	4.1%
Total PM-10	3.6%	8.0%	8.9%	9.0%	8.6%
Carbonaceous PM-2.5	0.1%	0.2%	0.0%	0.2%	0.2%
Sulfate PM-2.5	12.3%	27.6%	30.7%	30.7%	29.4%
Nitrate PM-2.5	1.2%	3.2%	4.4%	4.5%	4.1%
Total PM-2.5	3.6%	8.1%	9.0%	9.1%	8.7%
Benzene[1]	-0.9%	4.7%	12.6%	19.4%	8.0%
1,3-Butadiene[1]	3.3%	6.5%	18.8%	23.4%	15.6%
Formaldehyde[1]	2.8%	-0.8%	-12.7%	-12.6%	-8.4%
Acetaldehyde[1]	4.3%	3.8%	34.7%	3.4%	2.5%
Total Toxics[1]	1.0%	3.9%	13.0%	12.4%	5.5%
Potency-Weighted Toxics[1]	3.3%	7.3%	21.0%	26.3%	16.7%

[1] Impacts reflect percentage reduction in on-road gasoline emissions only.

Exhibit F.4B: Gasoline Option Impacts on Maricopa County Mobile Source (On-Road plus Off-Road) Emission Inventories (Percent Reduction)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2010 (January 1)					
Wintertime CO	0.3%	2.9%	1.6%	5.0%	4.3%
Wintertime VOC	0.9%	1.6%	0.9%	1.5%	1.4%
Wintertime NO_x	1.3%	3.2%	4.5%	4.5%	4.1%
Carbonaceous PM-10	0.1%	0.2%	0.0%	0.2%	0.2%
Sulfate PM-10	10.7%	24.0%	26.7%	26.7%	25.6%
Nitrate PM-10	1.3%	3.2%	4.5%	4.5%	4.1%
Total PM-10	3.2%	7.1%	7.9%	8.0%	7.6%
Carbonaceous PM-2.5	0.1%	0.2%	0.0%	0.1%	0.1%
Sulfate PM-2.5	10.7%	24.0%	26.7%	26.7%	25.6%
Nitrate PM-2.5	1.3%	3.2%	4.5%	4.5%	4.1%
Total PM-2.5	3.2%	7.2%	7.9%	8.0%	7.7%
Benzene	-0.9%	4.7%	12.6%	19.4%	8.0%
1,3-Butadiene	3.3%	6.5%	18.8%	23.4%	15.6%
Formaldehyde	2.8%	-0.8%	-12.7%	-12.6%	-8.4%
Acetaldehyde	4.3%	3.8%	34.8%	3.4%	2.6%
Total Toxics	1.0%	4.0%	13.1%	12.5%	5.6%
Potency-Weighted Toxics	3.3%	7.3%	21.1%	26.3%	16.7%

[1] Impacts reflect percentage reduction in on-road gasoline emissions only.

APPENDIX G: EMISSION REDUCTIONS BY MOBILE SOURCE SECTOR

The aggregate (i.e., combined on-road vehicle and off-road engine) emission reduction impacts of the wintertime gasoline and year-round diesel fuel options were presented in Section 6. Specifically, Tables 6.3A and 6.3B present the emission reduction impacts of the wintertime gasoline options and Tables 6.4A and 6.4B present corresponding impacts for the year-round diesel fuel options.

This appendix consists of a series of exhibits which present the emission reduction impacts estimated for the on-road vehicle and off-road engine sectors separately. These exhibits allow the impacts in each of the sectors to be compared in terms of their relative contributions to the total emission reduction impacts presented in Section 6. While it is clear that significant emission reductions are derived in each sector, the following general trends are noted:

- The greatest wintertime gasoline emission reductions accrue in the on-road sector,
- The greatest summertime diesel emission reduction impacts accrue in the off-road sector,
- The greatest wintertime diesel emission reduction impacts accrue in the on-road sector, and
- On an annual basis, off-road diesel particulate reduction impacts exceed those of the on-road sector by a factor of 3-7 times.

Exhibit G.1A: On-Road Emission Reductions for Gasoline Options (metric tons per day)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2001 (January 1)					
Wintertime CO	3.47	19.12	12.91	29.85	26.32
Calendar Year 2004 (January 1)					
Wintertime VOC	0.85	1.59	0.93	1.46	1.42
Wintertime NO_x	2.92	7.49	10.47	10.55	9.71
Carbonaceous PM-10	0.01	0.01	0.01	0.01	0.01
Sulfate PM-10	0.41	0.93	1.04	1.04	0.99
Nitrate PM-10	0.04	0.10	0.13	0.13	0.12
Total PM-10	0.46	1.04	1.18	1.18	1.13
Carbonaceous PM-2.5	0.00	0.01	0.01	0.01	0.01
Sulfate PM-2.5	0.37	0.84	0.93	0.93	0.90
Nitrate PM-2.5	0.03	0.08	0.11	0.11	0.10
Total PM-2.5	0.41	0.93	1.04	1.05	1.00
Benzene	-0.02	0.14	0.35	0.54	0.23
1,3-Butadiene	0.02	0.04	0.12	0.14	0.10
Formaldehyde	0.02	-0.01	-0.09	-0.09	-0.06
Acetaldehyde	0.03	0.03	0.27	0.03	0.02
Total Toxics	0.06	0.20	0.64	0.61	0.28
Potency-Weighted Toxics	0.02	0.06	0.18	0.23	0.13

Exhibit G.1B: On-Road Emission Reductions for Gasoline Options (metric tons per day)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2010 (January 1)					
Wintertime CO	2.89	15.75	10.69	24.53	21.65
Wintertime VOC	0.86	1.61	0.95	1.47	1.44
Wintertime NO_x	3.10	7.93	11.06	11.14	10.26
Carbonaceous PM-10	0.01	0.01	0.01	0.01	0.01
Sulfate PM-10	0.41	0.93	1.03	1.03	0.99
Nitrate PM-10	0.04	0.10	0.15	0.15	0.14
Total PM-10	0.46	1.04	1.18	1.19	1.13
Carbonaceous PM-2.5	0.00	0.01	0.01	0.01	0.01
Sulfate PM-2.5	0.37	0.83	0.93	0.93	0.89
Nitrate PM-2.5	0.03	0.08	0.12	0.12	0.11
Total PM-2.5	0.41	0.93	1.05	1.05	1.01
Benzene	-0.02	0.14	0.36	0.54	0.23
1,3-Butadiene	0.02	0.04	0.12	0.14	0.10
Formaldehyde	0.02	-0.01	-0.10	-0.09	-0.06
Acetaldehyde	0.03	0.03	0.27	0.03	0.02
Total Toxics	0.06	0.20	0.65	0.62	0.28
Potency-Weighted Toxics	0.02	0.06	0.18	0.23	0.13

Exhibit G.2A: Off-Road Emission Reductions for Gasoline Options (metric tons per day)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2001 (January 1)					
Wintertime CO	-0.98	0.62	-1.43	2.85	2.15
Calendar Year 2004 (January 1)					
Wintertime VOC	0.05	0.08	-0.01	0.05	0.05
Wintertime NO_x	0.00	0.01	0.02	0.02	0.02
Carbonaceous PM-10	0.01	0.02	0.00	0.01	0.01
Sulfate PM-10	0.35	0.79	0.87	0.87	0.84
Nitrate PM-10	0.00	0.00	0.00	0.00	0.00
Total PM-10	0.36	0.80	0.87	0.89	0.85
Carbonaceous PM-2.5	0.01	0.02	0.00	0.01	0.01
Sulfate PM-2.5	0.31	0.71	0.79	0.79	0.75
Nitrate PM-2.5	0.00	0.00	0.00	0.00	0.00
Total PM-2.5	0.32	0.72	0.78	0.80	0.76
Benzene	-0.01	0.00	0.03	0.05	0.02
1,3-Butadiene	0.00	0.00	0.01	0.02	0.01
Formaldehyde	0.00	0.00	-0.01	-0.01	-0.01
Acetaldehyde	0.00	0.00	0.03	0.00	0.00
Total Toxics	0.00	0.01	0.06	0.06	0.02
Potency-Weighted Toxics	0.00	0.00	0.02	0.02	0.01

Exhibit G.2B: Off-Road Emission Reductions for Gasoline Options (metric tons per day)

Pollutant	FedRFG2 80 ppmS	FedRFG2 30 ppmS	CalRFG2 2.0 %O_2	CalRFG2 3.5 %O_2	Performnc Standard
Calendar Year 2010 (January 1)					
Wintertime CO	-1.28	0.81	-1.87	3.72	2.81
Wintertime VOC	0.04	0.07	-0.01	0.04	0.04
Wintertime NO_x	0.00	0.01	0.03	0.03	0.02
Carbonaceous PM-10	0.02	0.03	0.00	0.02	0.02
Sulfate PM-10	0.43	0.96	1.06	1.06	1.02
Nitrate PM-10	0.00	0.00	0.00	0.00	0.00
Total PM-10	0.44	0.98	1.06	1.08	1.04
Carbonaceous PM-2.5	0.01	0.02	0.00	0.01	0.01
Sulfate PM-2.5	0.38	0.86	0.96	0.96	0.92
Nitrate PM-2.5	0.00	0.00	0.00	0.00	0.00
Total PM-2.5	0.40	0.88	0.95	0.97	0.93
Benzene	-0.01	0.00	0.03	0.05	0.01
1,3-Butadiene	0.00	0.00	0.01	0.01	0.01
Formaldehyde	0.00	0.00	-0.01	-0.01	-0.01
Acetaldehyde	0.00	0.00	0.03	0.00	0.00
Total Toxics	0.00	0.01	0.05	0.05	0.02
Potency-Weighted Toxics	0.00	0.00	0.02	0.02	0.01

Exhibit G.3A: On-Road Emission Reductions for Diesel Options
(metric tons per day)

Pollutant	EPA +5 Cetane	EPA +5C 100 ppmS	CARB Formula	CARB Certified	Advanced Blend	Swedish Class I
Calendar Year 1999 (July 1)						
Summertime VOC	1.37	1.34	1.13	2.21	2.88	2.11
Summertime NO_x	0.76	1.25	3.56	2.73	4.44	6.16
Summertime CO	6.05	6.09	6.49	10.82	14.83	8.47
Calendar Year 2001 (January 1)						
Wintertime CO	3.33	3.35	3.58	5.96	8.17	4.67
Calendar Year 2004 (January 1)						
Wintertime VOC	1.73	1.69	1.42	2.79	3.63	2.65
Wintertime NO_x	0.76	1.24	3.55	2.73	4.44	6.15
Calendar Year 2010 (January 1)						
Wintertime CO	3.55	3.57	3.81	6.35	8.71	4.97
Wintertime VOC	2.01	1.97	1.66	3.24	4.22	3.09
Wintertime NO_x	0.78	1.28	3.65	2.80	4.56	6.33
Calendar Year 2010 (July 1)						
Summertime VOC	1.51	1.48	1.25	2.44	3.17	2.32
Summertime NO_x	0.81	1.33	3.81	2.93	4.76	6.60
Summertime CO	7.95	8.00	8.53	14.21	19.48	11.12

Exhibit G.3B: On-Road Emission Reductions for Diesel Options (metric tons per year)

Pollutant	EPA +5 Cetane	EPA +5C 100 ppmS	CARB Formula	CARB Certified	Advanced Blend	Swedish Class I
Calendar Year 2004						
Carbonaceous PM-10	16	32	90	65	105	285
Sulfate PM-10	0	78	7	50	83	142
Nitrate PM-10	7	12	34	26	42	59
Total PM-10	24	123	131	141	231	486
Carbonaceous PM-2.5	15	29	81	59	96	259
Sulfate PM-2.5	0	70	6	45	75	128
Nitrate PM-2.5	6	9	27	21	34	47
Total PM-2.5	21	109	115	125	204	434
Calendar Year 2010						
Carbonaceous PM-10	12	24	67	48	78	212
Sulfate PM-10	0	80	7	51	85	145
Nitrate PM-10	8	13	36	28	45	62
Total PM-10	20	117	110	127	208	420
Carbonaceous PM-2.5	12	23	64	46	75	203
Sulfate PM-2.5	0	72	7	46	77	131
Nitrate PM-2.5	6	10	29	22	36	50
Total PM-2.5	18	105	99	114	187	384

Exhibit G.4A: Off-Road Emission Reductions for Diesel Options (metric tons per day)

Pollutant	EPA +5 Cetane	EPA +5C 100 ppmS	CARB Formula	CARB Certified	Advanced Blend	Swedish Class I
Calendar Year 1999 (July 1)						
Summertime VOC	3.04	2.98	2.51	4.91	6.38	4.67
Summertime NO_x	1.05	1.71	4.90	3.76	6.12	8.48
Summertime CO	8.29	8.35	8.90	14.83	20.33	11.61
Calendar Year 2001 (January 1)						
Wintertime CO	1.83	1.84	1.96	3.27	4.49	2.56
Calendar Year 2004 (January 1)						
Wintertime VOC	0.94	0.92	0.77	1.51	1.96	1.44
Wintertime NO_x	0.30	0.48	1.38	1.06	1.72	2.39
Calendar Year 2010 (January 1)						
Wintertime CO	2.76	2.77	2.96	4.93	6.76	3.86
Wintertime VOC	1.19	1.16	0.98	1.92	2.49	1.83
Wintertime NO_x	0.35	0.57	1.63	1.25	2.04	2.83
Calendar Year 2010 (July 1)						
Summertime VOC	4.76	4.66	3.92	7.67	9.98	7.31
Summertime NO_x	1.38	2.27	6.48	4.97	8.09	11.22
Summertime CO	14.27	14.35	15.31	25.51	34.97	19.96

Exhibit G.4B: Off-Road Emission Reductions for Diesel Options (metric tons per year)

Pollutant	EPA +5 Cetane	EPA +5C 100 ppmS	CARB Formula	CARB Certified	Advanced Blend	Swedish Class I
Calendar Year 2004						
Carbonaceous PM-10	61	121	334	242	392	1062
Sulfate PM-10	0	153	14	98	163	279
Nitrate PM-10	7	12	34	26	42	58
Total PM-10	68	286	381	366	597	1399
Carbonaceous PM-2.5	58	116	319	232	375	1016
Sulfate PM-2.5	0	138	13	88	147	251
Nitrate PM-2.5	6	9	27	21	34	47
Total PM-2.5	64	263	359	340	556	1314
Calendar Year 2010						
Carbonaceous PM-10	85	168	464	337	545	1476
Sulfate PM-10	0	248	23	158	264	451
Nitrate PM-10	8	14	39	30	49	68
Total PM-10	93	430	525	524	857	1995
Carbonaceous PM-2.5	81	161	444	323	522	1414
Sulfate PM-2.5	0	223	20	142	237	406
Nitrate PM-2.5	7	11	31	24	39	54
Total PM-2.5	88	395	496	489	798	1874